VOL. XXXVII. JANUARY, 1889.

Established by BENJAMIN SILLIMAN in 1818.

THE

AMERICAN

JOURNAL OF SCIENCE.

EDITORS

JAMES D. AND EDWARD S. DANA.

ASSOCIATE EDITORS

PROFESSORS JOSIAH P. COOKE, GEORGE L. GOODALE AND JOHN TROWBRIDGE, OF CAMBRIDGE.

PROFESSORS H. A. NEWTON AND A. E. VERRILL, OF NEW HAVEN,

PROFESSOR GEORGE F. BARKER, OF PHILADELPHIA.

THIRD SERIES.

VOL. XXXVII.—[WHOLE NUMBER, CXXXVII.]

No. 217.—JANUARY, 1889.

WITH PLATES I AND II.

NEW HAVEN, CONN.: J. D. & E. S. DANA.
1889.

TUTTLE, MOREHOUSE & TAYLOR, PRINTERS, 371 STATE STREET.

Published monthly. Six dollars per year (postage prepaid). $6.40 to foreign subscribers of countries in the Postal Union. Remittances should be made either by money orders, registered letters, or bank checks.

LITTELL'S LIVING AGE.

IN 1889 THE LIVING AGE enters upon its forty-sixth year. Approved in the outset by Judge Story, Chancellor Kent, President Adams, historians Sparks, Prescott, Ticknor, Bancroft, and many others, it has met with constant commendation and success.

A WEEKLY MAGAZINE, it gives fifty-two numbers of sixty-four pages each, or more than **Three and a Quarter Thousand** double-column octavo pages of reading-matter yearly. It presents in an inexpensive form, considering its great amount of matter, with freshness, owing to its weekly issue, and with a completeness nowhere else attempted,

The best Essays, Reviews, Criticisms, Tales, Sketches of Travel and Discovery, Poetry, Scientific, Biographical, Historical, and Political Information, from the entire body of Foreign Periodical Literature, and from the pens of

The Foremost Living Writers.

The ablest and most cultivated intellects, in every department of Literature, Science, Politics, and Art, find expression in the Periodical Literature of Europe, and especially of Great Britain.

The Living Age, forming four large volumes a year, furnishes from the great and generally inaccessible mass of this literature the only compilation that, while within the reach of all, is satisfactory in the COMPLETENESS with which it embraces whatever is of immediate interest, or of solid, permanent value.

It is therefore indispensable to every one who wishes to keep pace with the events or intellectual progress of the time, or to cultivate in himself or his family general intelligence and literary taste.

OPINIONS.

"No man who understands the worth and value of this sterling publication would think of doing without it. . Nowhere else can be found such a comprehensive and perfect view of the best literature and thought of our times. . Every article is an apple of gold in a picture of silver. . It furnishes to all the means to keep themselves intelligently abreast of the time."—*Christian at Work, New York.*

"It is a *living* picture of the age on its literary side. It was never brighter, fresher, or more worthy of its wide patronage. . To glance at its table of contents is in itself an inspiration. . No man will be behind the literature of the times who reads THE LIVING AGE."—*Zion's Herald, Boston.*

"Perennial in its attractions for the intelligent reader. It is one of those few publications, weekly or monthly, which seem indispensable. . The only possible objection that could be urged to it is the immense amount of reading it gives. . There is nothing noteworthy in science, art, literature, biography, philosophy, or religion, that cannot be found in it. It is a library in itself. . Such a publication exhausts our superlatives."—*The Churchman, New York*

"Replete with all the treasures of the best current thought, the best fiction, and the best poetry of the day. . It stands unrivalled."—*The Presbyterian, Phila.*

"The more valuable to a man, the longer he takes it. He comes to feel that he cannot live without it."—*New-York Evangelist.*

"Years of acquaintance with its weekly issues have impressed us more and more with a sense of its value and importance in an age when knowledge has increased beyond all precedent, and the multiplication of publications of all sorts makes it impossible for any one to keep up with the current. By the careful and judicious work put into the editing of THE LIVING AGE, it is made possible for the busy man to know something of what is going on with ever increasing activity in the world of letters. Without such help he is lost."—*Episcopal Recorder, Philadelphia.*

"Through its pages alone it is possible to be as well informed in current literature as by the perusal of a long list of monthlies."—*Philadelphia Inquirer.*

"The readers miss very little that is important in the periodical domain."—*Boston Journal.*

"One of the few periodicals worth keeping in a library. . It maintains its leading position in spite of the multitude of aspirants for public favor."—*New-York Observer.*

"Its value can hardly be reckoned in dollars and cents. . A repository of the best thought of the best writers of our day and generation."—*Boston Commonwealth.*

"Biography, fiction, science, criticism, history, poetry, travels, whatever men are interested in, all are found here."—*The Watchman, Boston.*

"It may be truthfully and cordially said that it never offers a dry or valueless page."—*New-York Tribune.*

"It is edited with great skill and care, and its weekly appearance gives it certain advantages over its monthly rivals."—*Albany Argus.*

"It saves much labor for busy people who wish to keep themselves well informed upon the questions of the day."—*The Advance, Chicago.*

"Still holds its foremost place."—*Troy Times.*

"Continually increases in value."—*Every Evening, Wilmington, Del.*

"It furnishes a complete compilation of an indispensable literature."—*Chicago Evening Journal.*

"Recent numbers show the wide range of thought and careful discrimination of editorship which have so long distinguished it. . For the amount of reading-matter contained the subscription is extremely low."—*Christian Advocate, Nashville.*

"It enables its readers to keep fully abreast of the best thought and literature of civilization."—*Christian Advocate, Pittsburgh.*

"In this weekly magazine the reader finds all that is worth knowing in the realm of current literature. . As a weekly record of the literary and scientific progress of the age it is indispensable."—*Canada Presbyterian, Toronto.*

"Rarely, indeed, will the seeker of what is most noteworthy in periodical literature be disappointed if he turns to THE LIVING AGE. . Coming once a week, it gives, while yet fresh, the productions of the foremost writers of the day. . It is a reflection, as its name implies, of the best life and thought of the age, and as such is indispensable to all who would keep abreast of our manifold progress. . It is absolutely without a rival."—*Montreal Gazette.*

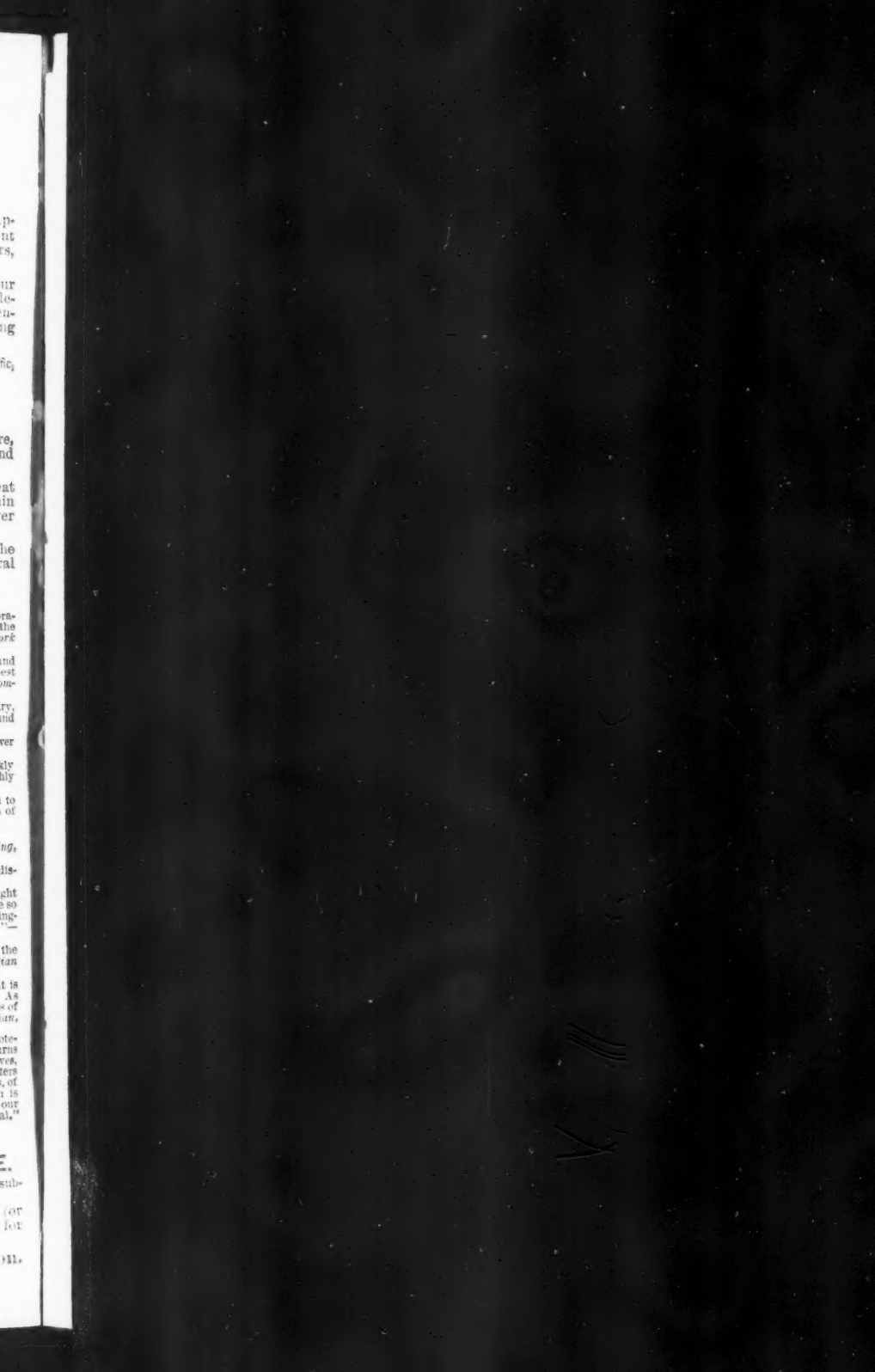
PUBLISHED WEEKLY at $8.00 a year, *free of postage.*

CLUB PRICES FOR THE BEST HOME AND FOREIGN LITERATURE.

["Possessed of LITTELL'S LIVING AGE, and of one or other of our vivacious American monthlies, a subscriber will find himself *in command of the whole situation.*"—*Philadelphia Evening Bulletin.*]

For $10.50, THE LIVING AGE and any one of the *four-dollar* monthly magazines (or *Harper's Weekly* or *Bazar*) will be sent for a year, with postage prepaid on both; or, for $9.50, THE LIVING AGE and the *St. Nicholas* or *Scribner's Magazine*, postpaid.

ADDRESS **LITTELL & CO., 31 Bedford St., Boston.**



THE

AMERICAN JOURNAL OF SCIENCE

[THIRD SERIES.]

ART. I.—*The History of a Doctrine;* Address by S. P. LANGLEY, retiring President of the American Association for the Advancement of Science.*

"Man, being the servant and interpreter of nature, can do and understand so much, and so much only, as he has observed, in fact or in thought, of the course of nature. Beyond this he neither knows anything nor can do anything."—BACON'S *Novum Organum*, aphorism 1.

IN these days, when a man can take but a very little portion of knowledge to be his province, it has become customary that your president's address shall deal with some limited topic, with which his own labors have made him familiar; and accordingly I have selected as my theme, the history of our present views about radiant energy, not only because of the intrinsic importance of the subject, but because the study of this energy in the form of radiant heat is one to which I have given special attention.

Just as the observing youth, who leaves his own household to look abroad for himself, comes back with the report that the world, after all, is very like his own family, so may the specialist, when he looks out from his own department, be surprised to find that, after all, the history of the narrowest specialty is strangely like that of scientific doctrine in general, and contains the same lessons for us. To find some of the most useful ones, it is important, however, to look with our own eyes at the very words of the masters themselves, and to

* This Address appears here complete with the notes that have not hitherto been published.—EDS.

take down the dusty copy of Newton, or Boyle, or Leslie, instead of a modern abstract; for, strange as it may seem, there is something of great moment in the original that has never yet been incorporated into any encyclopædia, something really essential in the words of the man himself which has not been indexed in any text-book, and never will be.

It is not for us, then, here to-day, to try

> "How index-learning turns no student pale,
> Yet holds the eel of science by the tail;"

but, on the contrary, to remark that from this index-learning, from these histories of science and summaries of its progress, we are apt to get wrong ideas of the very conditions on which this progress depends. We often hear it, for instance, likened to the march of an army towards some definite end; but this, it has seemed to me, is not the way science usually does move, but only the way it seems to move in the retrospective view of the compiler, who probably knows almost nothing of the real confusion, diversity, and retrograde motion of the individuals comprising the body, and only shows us such parts of it as he, looking backward from his present standpoint, now sees to have been in the right direction.

I believe this comparison of the progress of science to that of an army, which obeys an impulse from one head, has more error than truth in it; and, though all similes are more or less misleading, I would prefer to ask you to think rather of a moving crowd, where the direction of the whole comes somehow from the independent impulses of its individual members; not wholly unlike a pack of hounds, which, in the long-run, perhaps catches its game, but where, nevertheless, when at fault, each individual goes his own way, by scent not by sight, some running back and some forward; where the louder-voiced bring many to follow them, nearly as often in a wrong path as in a right one; where the entire pack even has been known to move off bodily on a false scent; for this, if a less dignified illustration, would be one which had the merit of having a truth in it, left out of sight by the writers of text-books.

At any rate, the actual movement has been tortuous, or often even retrograde, to a degree of which you will get no idea from the account in the text-book or encyclopædia, where, in the main, only the resultant of all these vacillating motions is given. With rare exceptions, the backward steps—that is, the errors and mistakes, which count in reality for nearly half, and sometimes for more than half, the whole—are left out of scientific history; and the reader, while he knows that mistakes have been made, has no just idea how intimately error and

truth are mingled in a sort of chemical union, even in the work of the great discoverers, and how it is the test of time chiefly, which enables us to say which *is* progress, when the man himself could not. If this be a truism, it is one which is often forgotten, and which we shall do well to here keep before us.

This is not the occasion to review the vague speculations of the ancient natural philosophers from Aristotle to Zeno, or to give the opinion of the schoolmen on our subject. We take it up with the immediate predecessors of Newton, among whom we may have been prepared to expect some obscure recognition of heat as a mode of motion, but where it has been, to me at least, surprising, on consulting their original works, to find how general and how clear an anticipation of our modern doctrine may be fairly said to exist. Whether this early recognition be a legacy from the Lucretian philosophy, it is not necessary to here consider. The interesting fact, however it came about, is the extent to which seventeenth century thought is found to be occupied with views which we are apt to think very recent.

Descartes, in 1664, commences his "Le Monde" by a treatise on the propagation of light, and what we should now call radiant heat by vibrations, and further associates this view of heat as motion with the distinct additional conception, that in the cause of light and radiant heat we may expect to find something quite different from the sense of vision or of warmth ;* and he expresses himself with the aid of the same simile of sound employed by Draper over two hundred years later. The writings of Boyle on the mechanical production of heat †

* "Me proposant de traiter ici de la lumière, la première chose dont je veux vous avertir est qu'il peut y avoir de la différence entre le sentiment que nous en avons, c'est-à-dire l'idée qui s'en forme en notre imagination par l'entremise de nos yeux, et ce qui est dans les objets qui produit en nous ce sentiment, c'est-à-dire ce qui est dans la flamme ou dans le soleil qui s'appelle du nom de lumiere: la plupart des philosophes assurent que le son n'est autre chose qu'un certain tremblement d'air qui vient frapper nos oreilles; en sorte que si le sens de l'ouïe rapportoit à notre pensée la vraie image de son objet, il faudroit, au lieu de nous faire concevoir le son, qu'il nous fît concevoir le mouvement des parties de l'air qui tremble pour lors contre nos oreilles. * * On passe doucement une plume sur les lèvres d'un enfant qui s'endort, et il sent qu'on le chatouille: pensez-vous que l'idée du chatouillement qu'il conçoit ressemble à quelque chose de ce qui est en cette plume?

† Detached passages from Bacon, Hobbes, and Locke, referring to the conception of heat, as a mode of motion, have been so often cited, that I will not repeat them here; but as these after all convey rather an impression of the acuteness of their authors, as men before their time, than the idea of a doctrine fully and clearly apprehended at the time, I prefer to offer the following much less known quotation, which I find in the works of Boyle, published *circa* 1670.

I beg the attention of the reader to the remarkable passages which follow, and which must have had, in Newton's day, all the currency which the eminent reputation of the author (a founder of the Royal Society) could give.

Extracts from the treatise on the "Mechanical Origin of Heat," by the Honorable Robert Boyle.—"Heat will appear the more likely to be mechanically producible,

contain illustrations (like that of the hammer driving the nail, which grows hot in proportion as its bodily motion is arrested) which show a singularly complete apprehension of views we

if we consider the nature of it, which seems to consist mainly, if not only, in that mechanical affection of matter we call local motion mechanically modified, which modification, as far as I have observed, is made up of three conditions."

"The first of these is, that the agitation of the parts be vehement. Thus, in a heated iron, the vehement agitation of the parts may be easily inferred from the motion and hissing noise it imparts to drops of water, or spittle, that fall upon it. For it makes them hiss and boil, and quickly forces their particles to quit the form of a liquor, and fly into the air in the form of steams."

"The second is this, that the determinations be very various, some particles moving towards the right, some to the left hand, some directly upwards, some downwards, and some obliquely, etc. As a thoroughly ignited coal will appear every way red, and will melt wax, and kindle brimstone, whether the body be applied to the upper or to the lower, or to any other part of the burning coal. And congruously to this notion, though air and water be moved never so vehemently as in high winds and cataracts; yet we are not to expect that they should be manifestly hot, because the vehemency belongs to the progressive motion of the whole body."

"There is yet a third condition; namely, that the agitated particles, or at least the greatest number of them, be so minute, as to be singly insensible. For though a heap of sand, or dust itself, were vehemently and confusedly agitated by a whirlwind, the bulk of the grains or corpuscles would keep their agitation from being properly heat. If some attention be employed in considering the formerly proposed notion of the nature of heat, it may not be difficult to discern that the mechanical production of it may be divers ways affected. For by whatever ways the insensible parts of a body are put into a very confused and vehement agitation, by the same ways heat may be introduced into that body; agreeably to which doctrine, as there are several agents and operations by which this calorific motion (if I may so call it) may be excited, so there may be several ways of mechanically producing heat."

Boyle goes on to cite numerous experiments.

"Experiment VI. When, for example, a smith does hastily hammer a nail or such like piece of iron, the hammered metal will grow exceeding hot and yet there appears not anything to make it so, save the forcible motion of the hammer, which impresses a vehement and variously determined agitation of the small parts of the iron; which being a cold body before, by that superinduced commotion of its small parts becomes in divers senses hot. Again, if a somewhat large nail be driven by a hammer into a plank, or piece of wood, it will receive divers strokes on the head before it grow hot; but when it is driven to the head, so that it can go no further, a few strokes will suffice to give it a considerable heat; for whilst, at every blow of the hammer, the nail enters further and further into the wood, the motion that is produced is chiefly progressive, and is of the whole nail tending one way; whereas, when that motion is stopped, then the impulse given by the stroke, being unable either to drive the nail further on, or to destroy its entireness, must be spent in making a various vehement and intestine commotion of the parts among themselves, and in such an one we formerly observed the nature of heat to consist."

"Experiment VII. That I might also show that not only a sensible, but an intense degree of heat, may be produced in a piece of cold iron by local motion, I caused a bar of that metal to be nimbly hammered by two or three lusty men and these soon brought it to that degree of heat, that not only was it a great deal too hot to be safely touched, but probably would have kindled gun-powder."

Boyle goes on in the eighth experiment to illustrate the production of heat by friction by the use of a file, the whetting of a blade of a knife, the head of a piece of brass rubbed on the floor until it burns one's fingers, the heat of the axle-tree of a carriage by the friction of the wheel, and the common experiment of striking fire with a steel and flint, the latter as illustrating the instantaneity of the production of the heat.

are apt to think we have made our own; and it seems to me that any one who consults the originals will admit, that, though its full consequences have not been wrought out till our own time, yet the fundamental idea of heat as a mode of motion is so far from being a modern one, that it was announced in varying forms by Newton's immediate predecessors, by Descartes, by Bacon, by Hobbes, and in particular by Boyle, while Hooke and Huyghens merely continue their work, as at first does Newton himself.

If, however, Newton found the doctrine of vibrations already, so to speak, "in the air," we must, while recognizing that in the history of thought the new always has its root in the old, and that it is not given even to a Newton to create an absolutely new light, still admit that the full dawn of our subject properly begins with him, and admit, too, that it is a bright one, when we read in the "Optics" such passages as these:

"Do not all fixed bodies, when heated beyond a certain degree, emit light and shine, and is not this emission performed by the vibrating motions of their parts?" And again: "Do not several sorts of rays make vibrations of several bignesses?" And still again: "Is not the heat conveyed by the vibrations of a much subtler medium than air?"

Here is the undulatory theory; here is the connection of the ethereal vibrations with those of the material solid; here is "heat as a mode of motion;" here is the identity of radiant heat and light; here is the idea of wave-lengths. What a step forward this first one is! And the second?

The second is, as we know, backward. The second is the rejection of this, and the adoption of the corpuscular hypothesis, with which alone the name of Newton (a father of the undulatory theory) is, in the minds of most, associated to day.

Do not let us forget, however, that it was on the balancing of arguments from the facts then known, that he decided, and that perhaps it was rather an evidence of his superiority to Huyghens, that apprehending equally clearly with the latter the undulatory theory, he recognized also more clearly that this theory, as then understood, utterly failed to account for several of the most important phenomena. With an equally judicial mind, Huyghens would perhaps have decided so too, in the face of difficulties, all of which have not been cleared up even to-day. These two great men, then, each looked around in the then darkness as far as his light carried him. All beyond that was chance to each; and fate willed that Newton, whose light shone farther than his rivals, found it extend just far enough to show the entrance to the wrong way. He reaches the conclusion that we all know; one not only wrong in regard to light, but which bears pernicious results

on the whole theory of heat, since light being conceded to be material, radiant heat, if affiliated to light, must be regarded as material too, and Newton's influence is so permanent, that we shall see this strange conclusion drawn by the contemporaries of Herschel from his experiments made a hundred years later.

It would seem then that the result of this unhappy corpuscular theory was more far-reaching than we commonly suppose, and that it is hardly too much to say that the whole promising movement of that age toward the true doctrine of radiant energy is not only arrested by it, but turned the other way; so that in this respect the philosophy of fifty years later is actually farther from the truth than that of Newton's predecessors, and the immense repute of Newton as a leader, on the whole so rightly earned, here leads astray others than his conscious disciples, and, it seems to me, affects men's opinions on topics which appear at first far removed from those he discussed. The adoption of phlogiston was, as we may reasonably infer, facilitated by it, and remotely Newton is perhaps also responsible in part for the doctrine of caloric a hundred years later. After him, at any rate, there is a great backward movement. We have a distinct retrogression from the ideas of Bacon and Hobbes and Boyle. Night settles in again on our subject almost as thick as in the days of the schoolmen, and there seems to be hardly an important contribution to our knowledge, in the first part of the eighteenth century, due to a physicist.

"Physics, beware of metaphysics," said Newton,—words which physicists are apt so exclusively to quote, that it seems only due to candor to observe that the most important step, perhaps, in the fifty years which followed the "Optics," came from Berkeley, who, reasoning as a metaphysician, gave us during Newton's lifetime a conception wonderfully in advance of his age. Yet the "New Theory of Vision" was generally viewed by contemporary philosophers as only an amusing paradox, while "coxcombs vanquish[ed] Berkeley with a grin;" and this contribution to science,—an exceptional if not a unique instance of a great physical generalization reached by *a priori* reasoning,—though published in 1709, remains in advance of the popular knowledge even in these closing years of the nineteenth century.

In the meantime a new error had risen among men,—a new truth, as it seemed to them,—and a thing destined to have a strong reflex action on the doctrine of radiant energy. It began with the generalization of a large class of phenomena which we now associate with the action of oxygen, then of course unknown, a generalization useful in itself, and accompanied by an explanation which was not in its origin objec-

tionable. Let us consider, in illustration, any familiar instance of oxidation, and try to look first for what was reasonable in the eighteenth-century views of the cause of such phenomena.

A piece of dry wood has in it the power of giving out heat and light when set on fire; but after it is consumed there is left of it only inert ashes, which can give neither. Something, then, has left the wood in process of becoming ashes; virtue has gone out of it, or, as we should say, its potential energy has gone.

This is, so far, an important observation, extending over a wide range of phenomena, and, if it had presented itself to the predecessors of Newton, it would probably have been allied to the vibratory theories, and become proportionately fruitful. But to his disciples, and to chemists and others, who, without being perhaps disciples, were like all then, more or less consciously influenced by the materiality of the corpuscular theory, it appeared that this virtue also was a material emanation;—that this energy was an actual ingredient of the wood,—a crudeness of conception which seems most strange to us, but is not perhaps unaccountable in view of the then current thought.

I have said that the progress of science is not so much that of an army as of a crowd of searchers, and that a call in a false direction may be responded to, not by one only, but by the whole body. In illustration, observe that during the greater part of the entire eighteenth century, this doctrine was adopted by almost every chemist and by many physicists. It had as general an acceptance among chemists then as the kinetic theory of gases, for instance, has among physicists now, and, so far as time is any test of truth, it was tested more severely than the kinetic theory has yet been; for it was not only the lamp and guide of chemists, and to a great extent of physicists also, but it remained the time-honored and highest generalization of chemical science for over half a century, and it was accepted not so much as a conditional hypothesis, as a final guide, and a conquest for truth which should endure always. And now where is it? Dissipated so utterly from men's minds, that, to the unprofessional part of even an educated audience like this, "phlogiston," once a name to conjure with, has become an unmeaning sound.

There is no need to insist on the application of the obvious moral to hypotheses of our own day.

I have tried to recall for a moment all that "phlogiston" meant a little more than a hundred years ago, partly because it seems to me, that, though a chemical conception, physics is not blameless for it, but chiefly because before it quitted the world it appears to have returned to physics the wrong in a multi-

plied form, by generating an offspring specially inimical to true ideas about radiant heat, and which is represented by a yet familiar term. I mean "caloric."

This word is still used loosely as a synonym for heat, but has quite ceased to be the very definite and technical term it once was. To me it has been new to find that this so familiar word "caloric," so far as my limited search has gone, was apparently coined only toward the last quarter of the last century. It is not to be found in the earliest edition of Johnston's dictionary, and, as far as I can learn, appears first in the corresponding French form in the works of Fourcroy. It expressed an idea which was the natural sequence of the phlogiston theory, and which is another illustration that the evil which such theories do lives after them.

"Caloric" first seemingly appears, then, as a word coined by the French chemists, and meant originally to signify the unknown cause of the sensation heat, without any implication as to its nature. But words, we know, though but wise men's counters, are the money of fools; and this one very soon came to commit its users to an idea which was more likely to have had its origin in the mind of a chemist at that time than of any other,—the idea of the cause of heat as a material ingredient of the hot body; something not, it is true, having weight, but which it would have been only a slight extension of the conception, to think might one day be isolated by a higher chemical art, and exhibited in a tangible form.

We may desire to recognize the perverted truth which usually underlies error and gives it currency, and be willing to believe that even "caloric" may have had some justification for its existence; but this error certainly seems to have been almost altogether pernicious for nearly the next eighty years, and down even to our own time. With this conception as a guide to the philosophers of the last years of the eighteenth century, it is not, at any rate, surprising if we find that at the end of a hundred years from Newton the crowd seems to be still going constantly farther and farther away from its true goal.

The doctrine of caloric is, however, always recognized as an hypothesis more acceptable to chemists than to physicists, some of whom still stand out for the theories of Newton's predecessors, even through the darkest years; so that the old idea of heat, as a mode of motion, has by no means so utterly died that it does not appear here and there during the last century, and indeed, not only among philosophers, but even in a popular form.

In an old English translation of Father Regnault's compilation on physics, dated about 1730, I find, for instance, the

most explicit statement of the doctrine of heat as a mode of motion. Here heat is defined (with the aid of a simile due, I believe, to Boyle) as "any Agitation whatever of the insensible parts. Thus a Nail which is drove into the Wood by the stroke of a Hammer does not appear to be hot, because its immediate parts have but one common Movement. But should the Nail cease to drive, it would acquire a sensible Heat, because its insensible Parts which receive the Motion of the Hammer now acquire an agitation every way rapid." We certainly must admit that the user of this illustration had just and clear ideas; and the interesting point here appears to be, that as Father Regnault's was not an original work, but a mere compendium or popular scientific treatise of the period, we see, if only from this instance, that the doctrine of heat as a mode of motion was not confined to the great men of an earlier or a later time, but formed a part of the common pabulum during the eighteenth century to an extent that has been forgotten.

Although Prevost gave us his most material contribution about 1790, we have, it seems to me, on the whole, little to interest us during that barren time in the history of radiant energy called the eighteenth century,—a century in which science wore the pedant's cap and gown, and her students read the poem of Creation like grammarians, for its syntax;—a century whose latter years are given up, till near its very close, to bad *a priori* theories in our subject, except in the work of two Americans; for in the general dearth at this time of experiments in radiant heat, it is a pleasure to fancy Benjamin Franklin sitting down before the fire, with a white stocking on one leg and a black one on the other, to see which leg would burn first, and to recall again how Benjamin Thompson (Count Rumford) not only weighed "caloric" literally in the balance and found it wanting, but made that memorable experiment in the Munich foundries which showed that heat was perpetually and without limit created from motion.

It was in the last years of the century, too, that he provided for the medal called by his name, and which, though to be given for researches in heat and light, has, I believe, been allotted in nearly every instance to men, who, like Leslie, Malus, Davy, Brewster, Fresnel, Melloni, Faraday, Arago, Stokes, Maxwell, and Tyndall, have contributed toward the subject of radiant energy in particular.

We observe that before this time the scientific literature of the century scarcely considers the idea even of radiant heat, still less of radiant energy; so that we have been obliged here to discuss the views of its physicists about heat in general, heat and light in most minds being then distinct entities; all

the ways for pilgrims to this special shrine of truth being barred, like those in Bunyan's Pilgrim's Progress, by the two unfriendly giants who are here called Phlogiston and Caloric, so that there are few scientific pilgrims who do not pay them toll.

The last years of this century were destined to see the most remarkable experiments in heat made in the whole of the hundred; for the memoir of Rumford appeared in the Philosophical Transactions for 1798; and in the very year 1800 appeared in the same place Sir William Herschel's paper, in which he describes how he placed a thermometer in successive colors of the solar spectrum, finding the heat increase progressively from the violet to the red, and increase yet more beyond the red where there was no color or light whatever; so that there are, he observes, invisible rays as well as visible. More than that, the first outnumber the second; and these dark rays are found in the very source and fount of light itself. These dark rays can also be obtained, he observes, from a candle or a piece of non-luminous hot iron, and, what is very significant, they are found to pass through glass, and to be refracted by it like luminous ones.

And now Herschel, searching for the final verity through a series of excellent experiments, asks a question which shows that he has truth, so to speak, in his hands,—he asks himself the great question whether heat and light be occasioned by the same or different rays.

Remember the importance of this (which the querist himself fully recognized); remember, that, after long hunting in the blindfold search, he has laid hands, as we now know, on the truth herself, and then see him—let go. He decides that heat and light are not occasioned by the same rays, and we seem to see the fugitive escape from his grasp, not to be again fairly caught till the next generation.

I hardly know more remarkable papers than these of Herschel's in the Philosophical Transactions for 1800, or anything more instructive in little men's successes than in this great man's failure, which came in the moment of success. I would strongly recommend the reading of these remarkable original memoirs to any physicist who knows them only at second-hand.

One more significant lesson remains, in the effect of this on the minds of his contemporaries. Herschel's observation is to us almost a demonstration of the identity of radiant heat and light; but now, though the nineteenth century is opening, it is with the doctrine in the minds of most physicists, and perhaps of all chemists, that heat is occasioned by a certain material fluid. Phlogiston is by this time dead or dying, but Caloric is very much alive, and never more perniciously active than now,

when, for instance, years after Herschel's observation, we find this cited as "demonstrating the existence of caloric;"—which was, it seems, the way it looked to a contemporary.

In the year 1804 appeared what should be a very notable book in the history of our subject, written by Sir John Leslie, whose name survives perhaps in the minds of many students chiefly in connection with the "cube" which is still called after him.

Leslie, however, ought to be remembered as a man of original genius, worthy to be mentioned with Herschel and Melloni; and his, too, is one of the books which the student may be recommended to read, at least in part, in the original; not so much for the writer's instructive experiments (which will be found in our text-books) as for his most instructive mistakes, which the text-book will probably not mention.

He began by introducing the use of the simple instrument which bears his name, and a new and more delicate heat-measurer (the differential thermometer); and with these, and concave reflectors of glass and metal, he commenced experiments in radiant heat, than which, he tells us, no part of physical science then appeared so dark, so dubious, and so neglected. It is interesting, and it marks the degree of neglect he alludes to, that his first discovery was that different substances have different radiating and absorbing powers. It gives us a vivid idea of the density of previous ignorance, that it was left to the present century to demonstrate this elementary fact, and that Leslie, in view of such discoveries, says, "I was transported at the prospect of a new world emerging to view."

Next he shows that the radiating and absorbing powers are proportional, next that cold as well as heat seems to be radiated, and next undertakes to see whether this radiant heat has any affinity to light. He then experiments in the ability of radiant heat to pass through a transparent glass, which transmits light freely, and thinks he finds that none does pass. Radiant heat with him seems to mean heat from non-luminous sources; and the ability or non-ability of this to pass through glass, is to Leslie and his successors a most crucial test, and its failure to do so a proof that this heat is not affiliated to light.

Let us pause a moment here to reflect that we are apt to unconsciously assume, while judging from our own present standpoint where past error is so plain, that the false conclusion can only be chosen by an able, earnest, conscientious seeker, after a sort of struggle. Not so. Such a man is found welcoming the false with rapture, as very truth herself.

"What then," says Leslie, "is this calorific and frigorific fluid after which we are inquiring? It is not light, it has no relation to ether, it bears no analogy to the fluids, real or

imaginary, of magnetism and electricity. But why have recourse to invisible agents? *Quod petis, hic est.* It is merely the ambient AIR."

The capitals are Leslie's own, but ere we smile with superior knowledge, let us put ourselves in his place, and then we may comprehend the exultation with which he announces the identity of radiant heat and common air, for he feels that he is beginning a daring revolt against the orthodox doctrine of caloric; and so he is.

The first five years of this century are notable in the history of radiant energy, not only for the work of Leslie, and for the observation by Wollaston, Ritter, and others, of the so-called "chemical" rays beyond the violet, but for the appearance of Young's papers, reëstablishing the undulatory theory, which he indeed considered in regard to light, but which was obviously destined to affect most powerfully the theory of radiant energy in general.

We are now in the year 1804, or over a century and a quarter since the corpuscular theory was emitted, and during that time it has gradually grown to be an article of faith in a sort of scientific church, where Newton has come to be looked on as an infallible head, and his views as dogmas, about which no doubt is to be tolerated; but if we could go back to Cambridge in the year 1668, when the obscure young student, in no way conscious of his future pontificate, takes his degree (standing twenty-third on the list of graduates), we should probably find that he had already elaborated and greatly improved certain already current ideas into the undulatory theory of light, which he at any rate promulgated a few years later, and afterward, pressed with many difficulties, altered, as we now know, to an emissive one.

Probably, if we could have heard his own statement then, he would have told how sorely tried he was between these two opinions, and, while explaining to us how the wavering balance came to lean as it did, would have admitted, with the modesty proper to such a man, that there was a great deal to be said on either side. We may, at any rate, be sure that it would not be from the lips of Newton himself that we should have had this announced as a belief which was to be part of the rule of faith to any man of science.

But observe how, if science and theology look askance at each other, it is still true that some scientific men and some theologians have, at any rate, more in common than either is ready to admit; for at the beginning of this century Newton's followers, far less tolerant than their master, have made out of this modest man a scientific pontiff, and out of his diffident opinions a positive dogma, till as years go on, he comes to be

cited as so infallible that a questioning of these opinions is an offense deserving excommunication.

This has grown to be the state of things in 1804, when Young, a man possessing something of Newton's own greatness, ventures to put forward some considerations to show that the undulatory theory may be the true one, after all. But the prevalent and orthodox scientific faith was still that of the material nature of light; the undulatory hypothesis was a heresy, and Young a heretic. If his great researches had been reviewed by a physicist or a brother worker, who had himself trodden the difficult path of discovery, he might have been treated at least intelligently; but then, as always, the camp-followers, who had never been at the front, shouted from a safe position in the rear to the man in the dust of the fight, that he was not proceeding according to the approved rules of tactics; then, as always, these men stood between the public and the investigator, and distributed praise or blame.

If you wish to hear how the scientific heretic should be rebuked for his folly, listen to one who never made an observation, but, having a smattering of everything books could teach about every branch of knowledge, was judged by himself and by the public to be the fittest interpreter to it, of the physical science of this day. I mean Henry Brougham, the universal critic, the future Lord Chancellor of England, of whom it was observed, that, "if he had but known a little *law*, he would have known a little of everything." He uses the then all-powerful *Edinburgh Review* for his pulpit, and from it fulminates the condemnations of the church on the innovating memoir of the heretical Young.

"This paper," he says, "contains nothing which deserves the name of experiment or discovery; and it is, in fact, destitute of every species of merit. . . . first is another lecture, containing more fancies, more blunders, more unfounded hypotheses, more gratuitous fictions . . . and all from the fertile yet fruitless brain of the eternal Dr. Young. In our second number we exposed the absurdity of this writer's 'law of interference,' as it pleases him to call one of the most incomprehensible suppositions that we remember to have met with in the history of human hypotheses."

There are whole pages of it, but this is enough; and I cite this passage among many such at command, not only as an example of the way the undulatory theory was treated at the beginning of this century in the first critical journal of Europe, but as another example of the general rule that the same thing may appear intrinsically absurd, or intrinsically reasonable, according to the year of grace in which we hear of it. The great majority, even of students of science, must take

their opinions ready-made as to science in general; each knowing, so far as he can be said to know anything at first-hand, only that little corner which research has made specially his own.

The moral we can all draw, I think, for ourselves.

In spite of such criticism as this, the undulatory hypothesis of light made rapid way, and carried with it, one would now say, the necessary inference that radiant heat was due to undulations also. This was, however, no legitimate inference to those to whom radiant heat was still a fluid; and yet, in spite of all, the modern doctrine now begins to make visible progress.

A marked step is taken about 1811 by a young Frenchman, De la Roche, who deserves to be better remembered than he is, for he clearly anticipated some of Melloni's discoveries. De la Roche in particular shows that of two successive screens the second absorbs heat in a less ratio than the first; whence he, before any one else, I believe, derives the just and most important, as well as the then most novel conception, that radiant heat is of different *kinds*. He sees also, that, as a body is heated more and more, there is a gradual and continual advance not only in the amount of heat it sends out, but in the kind, so that, as the temperature still rises, the radiant heat becomes light by imperceptible gradations; and he concludes that heat and light are due to one simple agent, which, as the temperature rises yet more, appears more and more as light, or which, as the luminous radiation is absorbed, re-appears as heat. Very little of it, he observes, passes even transparent screens at low temperatures, but more and more does so as the temperature rises.

All this is a truism in 1888, but it appears admirably new as well as true in 1811; and if De la Roche had not been removed by an early death, his would have not improbably been the greatest name of the century in the history of our subject; an honor, however, which was in fact reserved for another.

The idea of the identity of light and radiant heat had by this time made such progress that the attempt to polarize the latter was made in 1818 by Berard. We have just seen in Herschel's case how the most sound experiment may lead to a wrong conclusion, if it controvert the popular view. We now have the converse of this in the fact that the zeal of those who are really in the right way may lead to unsound and inconclusive experiment; for Berard experimentally established, as it was supposed, the fact that obscure radiant heat can be polarized. So it can, but not with such means as Berard possessed, and it was not till a dozen years more that Forbes actually proved it.

At this time, however fairly we seem embarked on the paths of study which are followed to-day, and while the movement of the main body of workers is in the right direction, it is yet instructive to observe how eminent men are still spending great and conscientious labor, their object in which is to advance the cause, while the effect of it is to undo the little which has been rightly done, and to mislead those who have begun to go right.

As an instance both of this and of the superiority of modern apparatus, we may remark,—after having noticed that the ability of obscure heat to pass through glass, if completely established, would be a strong argument in favor of its kinship to light, and that De la Roche and others had indicated that it would do so (in which we now know they were right),—that at this stage, or about 1816, Sir David Brewster, the eminent physicist, made a series of experiments which showed that it would not so pass. Ten years later, in view of the importance of the theoretical conclusion, Baden Powell repeated his observations with great care, and confirmed them, announcing that the earlier experimenters were wrong, and that Brewster was right; so that here all these years of conscientious work resulted in establishing, so far as it could be established, a wholly wrong conclusion in place of a right one already gained.

It may be added, that with our present apparatus, the passage of obscure radiant heat through glass could be made convincingly evident in an experiment which need not last a single second.

We are now arrived at a time when the modern era begins; and in looking back over one hundred and fifty years, from the point of view of the experimenter himself with his own statement of the truth as he saw it, we find that the comparison of the progress of science to that of an army, which moves, perhaps with the loss of occasional men, but on the whole victoriously and in one direction, is singularly misleading; and I state this more confidently here, because there are many in this audience who did not get their knowledge of nature from books only, but who have searched for the truth themselves; and, speaking to them, may I not say that those who have so searched know that the most honest purpose and the most patient striving have not been guaranties against mistakes,—mistakes which were probably hailed at the time as successes? It was some one of the fraternity of seekers, I am sure, who said, "Show me the investigator who has never made a mistake, and I will show you one who has never made a discovery."

We have seen the whole scientific body, as regards this particular science of radiant energy, moving in a mass, in a wrong

direction, for a century; we have seen that individuals in it go on their independent paths of error; and we can only wonder that an era should have come in which such a real advance is made as in ours.

That era has been brought in by the works of many, but more than by any other through the fact that, in the year 1801, there came into the world at Parma an infant who was born a physicist, as another is born a poet; nay, more; who was born, one might say, a devotee of one department of physics, that of radiant heat; being affected in his tenderest years with such a kind of precocious passion for the subject as the childish Mozart showed for music. He was ready to sacrifice everything for it; he struggled through untold difficulties, not for the sake of glory or worldly profit, but for radiant heat's sake; and when fame finally came to him, and he had the right to speak of himself, he wrote a preface to his collected researches, which is as remarkable as anything in his works. In this preface he has given us, not a summary of previous memoirs on the subject, not a table of useful factors and formulæ, not anything at all that an English or an American scientific treatise usually begins with, but the ingenuous story of his first love, of his boyish passion for this beloved mistress; and all this with a trust in us, his readers, which is beautiful in its childlike confidence in our sympathy.

I should need to abbreviate and injure in order to quote; but did ever a learned physical treatise and collections of useful tables begin like this before?

"I was born at Parma, and when I got a holiday used to go into the country the night before, and go to bed early, so as to get up before the dawn. Then I used to steal silently out of the house, and run, with bounding heart, till I got to the top of a little hill, where I used to set myself so as to look toward the East." There, he tells us, he used, in the stillness of nature, to wait the rising sun, and feel his attention rapt, less with the glorious spectacle of the morning light itself than with the sense of the mysterious heat which accompanied its beams, and brought something more necessary to our life and that of all nature than the light itself, so that the idea that not only mankind, but nature, would perish though the light continued, if this was divorced from heat, made a profound impression, he tells us, on his childish mind.

The statement that such an idea could enter with dominating force into the mind of a child will perhaps seem improbable to most. It will, however, be credible enough to some here, I have no doubt.

Is there some ornithologist present who remembers a quite infantile attraction which birds possessed for him above all the

rest of the animated creation? Some chemist whose earliest recollections are of the strange and quite abnormal interest he found as a child in making experimental mixtures of every kind of accessible household fluid and solid? Some astronomer who remembers that when a very little creature not only the sight of the stars, but of any work on astronomy, even if utterly beyond his childish comprehension, had an incomprehensible attraction for him? I will not add to the list. There are, at any rate, many here who will understand Melloni when he tells how this radiant heat, commonplace to others, was wonderful to his childish thought, and wrought a charm on it such that he could not see wood burn in a fireplace, or look at a hot stove, without its drawing his mind, not to the fire or iron itself, but to the mysterious effluence which it sent.

This was the youth of genius; but let not any fancy that genius in research is to be argued from such premonitions alone, unless it can add to them that other qualification of genius which has caused it to be named the faculty of taking infinite pains. Melloni's subsequent labors justified this last definition also; but I cannot speak of them here, further than to say, that, after going over a large part of his work myself, with modern methods and with better apparatus, he seems to me the man, of all great students of our subject, who, in reference to what he accomplished, made the fewest mistakes.

Melloni is very great as an experimenter, and owes much of his success to the use of the newly invented thermopile, which is partly his own. I can here, however, speak only of his results, and of but two of these,—one generally known; the other, and the more important, singularly little known, at least in connection with him.

The first is the full recognition of the fact, partly anticipated by De la Roche, that radiant heat is of different kinds, and that the invisible emanations differ among themselves just as those of light do. Melloni not only established the fact, but invented a felicitous term for it, which did a great deal to stamp it on recognition,—the term "thermochrose," or heat-color, which helps us to remember, that, as the visible and apparently simple emanation of light is found to have its colors, so radiant heat, the invisible but apparently simple emanation, has what would be colors to an eye that could see them. This result is well known in connection with Melloni.

The other and the greater, which is not generally known as Melloni's, is the generalization that heat and light are effects of one and the same thing, and merely different manifestations of it. I translate this important statement as closely as possible from his own words. They are that

"*Light is merely a series of calorific indications sensible to the organs of sight, or vice versa, the radiations of obscure heat are veritable* INVISIBLE RADIATIONS *of light.*"

The italics and the capitals are Melloni's own. He wishes to have no ambiguity about his announcement behind which he may take shelter; and he had so firm a grasp of the great principle, that, when his first attempts to observe the heat of the moon failed, he persevered, because this principle assured him that where there was light there must be heat. This statement was made in 1843, and ought, I think, to insure to Melloni the honor of being first to thus distinctly announce this great generalization.

The announcement passed apparently unnoticed, in spite of his acknowledged authority; and the general belief not merely in different entities in the spectrum, but in a material caloric, continued as strong as ever. If you want to see what a hold on life error has, and how hard it dies, turn to the article "heat," in the eighth edition of the "Encyclopædia Britannica," where you will find the old doctrine of caloric still in possession of the field in 1853; and still later, in the generally excellent "English Encyclopædia" (edition of 1867), the doctrine of caloric is, on the whole, preferred to the undulatory hypothesis. It is very probable that a searcher might find many traces of it yet lingering among us; so that Giant Caloric is not, perhaps, even yet quite dead, though certainly grown so crazy and stiff in the joints, that he can now harm pilgrims no more.

So far as I know, no physicist of eminence reasserted Melloni's principle with equal emphasis, till J. W. Draper, in 1872. Only sixteen years ago, or in 1872, it was almost universally believed that there were three different entities in the spectrum, represented by actinic, luminous and thermal rays. Draper remarks that a ray consists solely of ethereal vibrations whose lost *vis viva* may produce either heat or chemical change. He uses Descartes' analogy of the vibration of the air, and sound; but he makes no mention either of Descartes or of Melloni, and speaks of the principle as leading to a modification of views then "universally" held. Since that time the theory has made such rapid progress, that, though some of the older men in England and on the European continent have not welcomed it, its adoption among all physicists of note may be said to be now universal, and a new era in our history begins with it. I mean with the recognition that there is one radiant energy which appears to us as "actinic," or "luminous" or "thermal" radiation, according to the way we observe it. Heat and light, then, are not things in themselves, but whether different sensations in our own bodies, or different effects in

other bodies, are merely effects of this mysterious thing we call radiant energy, without doing more in this than give a name to the ignorance which still hangs over the ultimate cause.

I am coming down dangerously near our own time, for one who would be impartial in dealing with names of those still living. In such a brief review of this century's study of radiant energy in other forms than light, it has been necessary to pass without mention the labors of such men as Pouillet and Becquerel in France, of Tyndall in England, and of Henry in America. It has been necessary to omit all mention of those who have advanced the knowledge of radiant energy as light, or I should have had to speak of labors so diverse as those of Fraunhofer, of Kirchhoff, of Fresnel, of Stokes, of Lockyer, of Janssen, and many more. I have made no mention, in the instructive history of error, of many celebrated experimental researches; in particular of such a problem as the measurement of solar heat, great in importance, but apparently most simple in solution, yet which has now been carried on from generation to generation, each experimenter materially altering the result of his predecessor, and where our successors will probably correct our own results in turn. I have not spoken of certain purely experimental investigations, like those of Dulong and Petit, which have involved immense and conscientious labor, and have apparently rightly earned the name of "classic" from one generation, only to be recognized by the next as leading to untrustworthy results, and leaving the work to be done again with new methods, guided by new principles.

In these instances, painstaking experiments have proved insufficient, less from want of skill in the investigator than from his ignorance of principles not established in time to enable him to interpret his experiments; but, if there were opportunity, it would be profitable to show how inexplicably sometimes error flourishes, grows, and maintains an apparently healthy appearance of truth, without having any root whatever. Perhaps I may cite one instance of this last from my own experience.

About ten years ago it was generally believed that the earth's atmosphere acted exactly the part of the glass in a hot-bed, and that it kept the planet warm by exerting a specially powerful absorption on all infra-red rays. I had been reared in the orthodox scientific church, of which I am happy to be still a member; but I had acquired perhaps an almost undue respect, not only for her doctrines, but for her least sayings. Accordingly, when my own experiments did not agree with the received statement, I concluded that my experiments must be wrong, and made them all over again, till spring, summer,

autumn and winter had passed, each season giving its own testimony; and this for successive years. The final conclusion was irresistible, that the universal statement of this alleged well-known fact, inexplicable as this might seem, in so simple a matter, was directly contradicted by experiment. I had some natural curiosity to find how every one knew this to be a fact; but search only showed the same statement (that the earth's atmosphere absorbed dark heat like glass) repeated everywhere, with absolutely nowhere any observation or evidence whatever to prove it, but each writer quoting from an earlier one, till I was almost ready to believe it a dogma superior to reason, and resting on the well-known "*Quod semper, quod ubique, quod ab omnibus, creditum est.*" Finally I appear to have found its source in the writings of Fourier, who, alluding to De Saussure's experiments (which showed that dark heat passed with comparative difficulty through glass) observes that if the earth's atmosphere were solid, it would act as the glass does. Fourier simply takes this (in which he is wrong) for granted; but, as he is an authority on the theory of heat, his words are repeated without criticism, first by Poisson, then by others, and then in the text-books; and, the statement gaining weight by age, it comes to be believed absolutely, on no evidence whatever, for the next sixty years, that our atmosphere is a powerful absorber of precisely those rays which it most freely transmits.

The question of fact here, though important, is, I think, quite secondary to the query it raises as to the possible unsuspected influence of mere tradition in science, when we do not recognize it as such. Now, members of any church are doubtless consistent in believing in traditions, if they believe that these are presented to them by an infallible guide; but are we, who have no infallible guide, quite safe in believing all we do, from our fond persuasion that in the scientific body mere tradition has no weight?

In even this brief sketch of the growth of the doctrine of radiant energy, we have perhaps seen that the history of the progress of this department of science is little else than a chapter in that larger history of human error which is still to be written, and which, it is safe to say, would include illustrations from other branches of science, as well as my own. But —and here I ask pardon if I speak of myself—I have been led to review the labors of other searchers from this standpoint, because I had first learned, out of personal experience, that the greatest care was no certain guaranty of final accuracy; that to labor in the search for a truth with such endless pains as a man might bestow if his own salvation were in question, did not necessarily bring the truth; and because, seeking to

see whether this were the lot of other and greater men, I have found that it was, and that, though no one was altogether forsaken of the truth he sought, or, on the whole review of his life as a seeker, but might believe he had advanced her cause, yet there was no absolute criterion by which it could be told at the time, whether, when after long waiting, there came in view what seemed once more her beautiful face, it might not possibly prove, after all, the mockery of error; and, doubtless, appeal might be made to the experience of many investigators here with the question, "Is it not so?"

What then? Shall we admit that truth is only to be surely found under the guidance of an infallible church? If there be such a church, yes! Let us, however, remember that the church of science is not such a one, and be ready to face all the consequences of the knowledge that her truths are put forward by her as provisional only, and that her most faithful children are welcome to disprove them.

What then, again? Shall we say that the knowledge of truth is not advancing? It is advancing, and never so fast as to-day; but the steps of its advance are set on past errors, and the new truths become such stepping-stones in turn.

To say that what are truths to one generation are errors to the next, or that truth and error are but different aspects of the same thing to our poor human nature, may be to utter truisms; but truisms which one has verified for one's self out of a personal experience are apt to have a special value to the owner; and these lead, at any rate, to the natural question, "Where is, then, the evidence that *we* are advancing in reality, and not in our own imagination?"

There are many here who will no doubt heartily subscribe to the belief that there is no absolute criterion of truth for the individual, and admit that there is no positive guaranty that we, with this whole generation of scientific men, may not, like our predecessors, at times go the wrong way in a body, yet who believe as certainly that science as a whole, and this branch of it in particular, is actually advancing with hitherto unknown rapidity. In asking to be included in this number, let me add that to me the criterion of this advance is not in any ratiocination, not in any *a priori* truth, still less in the dictum of any authority, but in the undoubted observation that our doctrine of radiant energy is reaching out in every direction, and proving itself by the equally undoubted fact that through its aid nature obeys us more and more; proving itself by such material evidence as is found in the electric lights in our streets, and in a thousand such ways which I need not pause to enumerate.

And here I might end, hoping that there may be some lessons for us in the history of what has been said. I will venture to ask attention to but one. It is that in these days, when the advantage of organization is so fully recognized, when there is a well-founded hope that by coöperation among scientific men knowledge may be more rapidly increased, and when not only in the great scientific departments of government but everywhere, there is a tendency to the formation of the divisions of a sort of scientific army, not to say of a scientific church—that at such a time we should yet remember, that, however rapidly science changes, human nature remains much the same; and (while we are uttering truisms) let us venture to repeat that there is a very great deal of this "human nature" even in the scientific man, whose best type is one nearly as independent as nature itself, and one which will not always work best at the word of command. Let him then never forget that the history of science, scarcely less than of theology, warns him of the tendency of authority to exceed its proper sphere, and from without it, to define belief, and to impose obedience to doctrine.

Finally, if, turning to the future, I were asked what I thought were the next great steps to be taken in the study of radiant heat, I should feel unwilling to attempt to look more than a very little way in advance. Immediately before us, however, there is one great problem waiting solution. I mean the relation between temperature and radiation; for we know almost nothing of this, where knowledge would give new insight into almost every operation of nature (nearly every one of which is accompanied by the radiation or reception of heat), and would enable us to answer inquiries now put to physicists in vain by every department of science, from that of the naturalist as to the enigma of the brief radiation of the glow-worm, to that of the geologist who asks as to the number of million years required for the cooling of a world.

When, however, we begin to go beyond the points which seem, like this, to invite our very next steps in advance, we cannot venture to prophesy, and must content ourselves with the knowledge that through our study we are beginning to apprehend the full meaning of one of the early great ones of science, who described man as the meeting point of two infinities. That there is an infinity of space above him, man has long known, but that there is another absolute infinity, and what the possibilities are which lie in the infinitesimals of space, he is but beginning to realize. The secular movements, whose accomplishment demands more than a million years of time, he has already considered; but of the consequences which may result from a more careful study of actions occurring in the

infinitesimals of time, and whose whole duration may be far less than the millionth of a second, he has hardly even yet begun to think; and these are but little portions of the ungarnered field of research, open to the student of that radiant energy which sustains, with our own being, that of all animated nature, of which humanity is but a part.

If there be any students of nature here, who, feeling drawn to labor in this great field of hers, still doubt whether there is yet room, surely it may be said to them, "Yes, just as much room as ever, as much room as the whole earth offered to the first man;" for everything that has been done in the past is, I believe, as nothing to what remains before us, and that field is simply unbounded. The days of hardest trial and incessant bewildering error in which your elders have wrought, seem over. You "in happier ages born," you of the younger and the coming race, who have a mind to enter in and possess it, may, as the last word here, be bidden to indulge in an equally unbounded hope.

ART. II.—*Description of the new mineral, Beryllonite;* by EDWARD S. DANA and HORACE L. WELLS. With Plate I.

IN the October number of this Journal a preliminary account was given by one of us* of a new phosphate of sodium and beryllium, for which the name *Beryllonite* was proposed. We purpose now to give a more complete account of this species, the unusual interest of which has been developed by fuller study.

Locality and occurrence.—The first specimens of beryllonite were discovered near Stoneham, Maine, in 1886, by Mr. Sumner Andrews of Lawrence, Massachusetts. The Stoneham region is already well known,† having afforded fine specimens of topaz, phenacite, herderite and many other species of greater or less interest. The exact locality of the beryllonite is situated in the west part of the town of Stoneham at the base of a small but steep mountain, known as the McKean mountain. At this spot, work was carried on‡ sometime since in the

* E. S. Dana, this Journal, xxxvi, 290, October, 1888; the chemical work of the present paper has been done by H. L. Wells.

† Cf. George F. Kunz, this Journal, xxv, 161, 1883, xxvii, 212, 1884, xxxvi, 222, 1888. W. E. Hidden, xxvii, 73, 125, 1884. Mr. Kunz has since announced that the topaz and phenacite locality is not in Stoneham but on Bald Face Mountain, North Chatham, New Hampshire, just across the State line; this is 6 or 7 miles west of the beryllonite locality. Herderite and topaz are found on Harndon Hill, Stoneham, about 4 miles southwest of the beryllonite locality.

‡ By Mr. E. D. Andrews.

search for smoky quartz and a considerable quantity was obtained, including one crystal weighing nearly 100 lbs. The beryllonite, however, was overlooked, being not unnaturally taken for colorless quartz.

The early specimens, like those which have been obtained since, were found either detached in the soil or occasionally imbedded in a loosely coherent brecciated mass obviously not the original matrix. The material in which the crystals and fragments occur has evidently been derived from a granitic vein, fragments of partly kaolinized feldspar, smoky quartz crystals and other species to be mentioned being common. The exploration thus far carried on, however, has not brought to light the vein in an unaltered condition, although an apparent vein 4 to 6 feet wide of decomposed material has been found. The country rock is mica schist, which has been met with at a number of points in the course of the excavations.

The species which have been obtained from the same spot associated with the new mineral, and which probably represent its original associates in the vein are the feldspars, orthoclase and albite, smoky quartz sometimes in large crystals, mica, also columbite, cassiterite, beryl, apatite, triplite. The crystals bear evidence of having been implanted upon the rock on one side as if they had occurred in cavities rather than completely embedded. Some specimens, however, retain the impressions of surrounding minerals, probably mica. A single specimen is implanted upon apatite and inclusions of apatite have been noted. The chemical agencies which have kaolinized the feldspar have also left their mark on the beryllonite the surfaces of which are often roughened or in some cases delicately etched.

Crystalline form.—The specimens in hand are in large part fragments of crystals, ranging from those presenting a surface of an inch or two square and weighing 40 to 50 grams down to the size of a pea. Well formed crystals are rare; the largest is somewhat more than an inch across. All the specimens show a highly perfect basal cleavage (*c*), yielding easily smooth lustrous surfaces. Exactly at right angles to this (measured 90° 0′ and 89° 59½′) is a second cleavage somewhat interrupted and obtained with a little difficulty; the third pinacoidal cleavage is faintly indicated in the rectangular form of some of the broken fragments, and a fourth cleavage is sometimes distinct parallel to a prism of 60°. Twins are common in which the twinning plane is a prism also of sensibly 60°,* but it is found that the twinning prism and the cleavage prism, though having nearly

* When the preliminary notice was written, no material was at hand allowing of exact measurement and it was assumed that of the two possible twinning planes, the one present was probably also the cleavage prism; this has since been shown not to be the case, hence the change of position here adopted.

the same angle, are not identical. Of the two positions suggested by these facts it has seemed best to follow the usage in most similar cases and make the twinning plane the unit prism. Adopting this, the second cleavage corresponds to the macropinacoid (a), the imperfect pinacoidal cleavage is brachydiagonal (b) and the cleavage prism has the symbol 130 (i-3).

The material at hand for exact measurement is very scanty. With very few exceptions the planes have lost their original luster, and give no reflections at all. A few angles, however, could be measured, and with sufficient exactness to yield a satisfactory axial ratio. For fundamental angles the following were accepted:

$$001 \wedge 111 = 47° 51\tfrac{1}{2}', \quad 001 \wedge 021 = 47° 40\tfrac{1}{2}'.$$

Each of these is the mean of two independent angles on different crystals of equal degrees of accuracy, not involving a probable error of more than $\pm 1'$; these are:

47° 51′ and 47° 52′, also 47° 40′ and 47° 41′.

The axial ratio obtained is:

$$\breve{a} : \bar{b} : \dot{c} = 0{\cdot}57243 : 1 : 0{\cdot}54901;$$ also the angles

$100 \wedge 110 = 29° 47' 17''$, $001 \wedge 101 = 43° 48' 13''$, $001 \wedge 011 = 28° 46' 2''$.

The measured angles, the symmetry in arrangement of the planes and optical characters all conform to the orthorhombic system. As confirming the accuracy of these elements we have:

	Measured.	Calculated.
$021 \wedge 02\bar{1}$ =	84° 41′	84° 39′
$023 \wedge 02\bar{3}$ =	139° 46′	139° 48′
$100 \wedge 130$ =	59° 45′ Cleavage.	59° 47′

On two crystals the angle aa was measured between cleavage faces and the result 120° 22′ obtained in each case. This would give as twinning plane, if coinciding with the composition plane, the angle on 100 of 29° 49′, or if at right angles to the composition face 60° 11′. The former is the more probable relation and is shown to be the true one by the fact that the calculated angle for $100 \wedge 110$ is 29° 47′, while for $100 \wedge 130$ it is 59° 47′.

In habit the crystals vary from short prismatic to tabular, as shown in figs. 1 to 6; the aspect changes considerably with the change in relative size of the pyramids; of these w (121, 2-2) is usually most prominent. The crystals are remarkable for the number of planes which they present. The prismatic and brachydome zones are both highly developed, and it is not uncommon to note the presence of eight or more distinct planes in each zone on a single crystal. It is also interesting

to note that eleven of the twelve prismatic planes have representatives in the brachydome series, and, furthermore, they have nearly equal angles, since the axes $\breve{a}$ and $\dot{c}$ have approximately the same length.

Some idea of the complexity of the form may be gained from fig. 8, which is a basal projection of a single crystal simplified by the omission of several minute but distinct planes. The prismatic faces are often narrow and by their oscillatory combination produce vertical striations, especially on *a*; the faces of the pyramid *v* also show sometimes striations parallel to the edge *v*/*f*. The list of planes observed is given below; this might be increased if it were thought worth while to include a number of forms the symbols of which could not be determined with accuracy.

a (100, $\dot{\imath}$-$\bar{\imath}$), *b* (010, $\dot{\imath}$-$\breve{\imath}$), *c* (001, *O*); prisms *g* (410, $\dot{\imath}$-$\bar{4}$), *h* (310, $\dot{\imath}$-$\bar{3}$), *i* (210, $\dot{\imath}$-$\bar{2}$), *j* (320, $\dot{\imath}$-$\frac{\bar{3}}{2}$), *m* (110, *I*), *k* (230, $\dot{\imath}$-$\frac{3}{2}$), *l* (120, $\dot{\imath}$-$\breve{2}$), *n* (130, $\dot{\imath}$-$\breve{3}$), *o* (140, $\dot{\imath}$-$\breve{4}$), *π* (150, $\dot{\imath}$-$\breve{5}$), *p* (160, $\dot{\imath}$-$\breve{6}$), *q* (1·12·0, $\dot{\imath}$-$\widetilde{12}$); macrodomes *d* (102, $\frac{1}{2}$-$\bar{\imath}$), *e* (101, 1-$\bar{\imath}$), *f* (201, 2-$\bar{\imath}$); brachydomes *α* (014, $\frac{1}{4}$-$\breve{\imath}$), *β* (013, $\frac{1}{3}$-$\breve{\imath}$), *γ* (012, $\frac{1}{2}$-$\breve{\imath}$), *δ* (023, $\frac{2}{3}$-$\breve{\imath}$), *ε* (011, 1-$\breve{\imath}$), *ζ* (032, $\frac{3}{2}$-$\breve{\imath}$), *η* (021, 2-$\breve{\imath}$), *ϑ* (031, 3-$\breve{\imath}$), *κ* (041, 4-$\breve{\imath}$), *λ* (051, 5-$\breve{\imath}$), *μ* (061, 6-$\breve{\imath}$); unit pyramids *ψ* (112, $\frac{1}{2}$), *v* (111, 1), *s* (221, 2), Δ (331, 3); macro-pyramids *R* (411, 4-$\bar{4}$); *u* (212, 1-$\bar{2}$), *r* (211, 2-$\bar{2}$), *T* (421, 4-$\bar{2}$); brachy-pyramids *φ* (232, 1-$\frac{\breve{3}}{2}$), *t* (231, 3-$\frac{\breve{3}}{2}$); *ρ* (123, $\frac{1}{3}$-$\breve{2}$), *χ* (122, 1-$\breve{2}$), *w* (121, 2-$\breve{2}$); *σ* (132, $\frac{3}{2}$-$\breve{3}$), *x* (131, 3-$\breve{3}$); *Q* (142, 2-$\bar{4}$), *y* (141, 4-$\bar{4}$); *z* (151, 5-$\breve{5}$); *τ* (163, 2-$\breve{6}$), *ω* (161, 6-$\breve{6}$).

It will be noted that all the planes have very simple symbols, and furthermore they are so tied together by zones that the symbols of a large part can be determined without measurement. The following are some of the prominent zones, after the pinacoidal zones: *e* (101), *u* (212), *v* (111), *φ* (232), *w* (121), *x* (131), *y* (141), *z* (151), *ω* (161); also *r* (211), *s* (221), *t* (231); again *ψ* (112), *χ* (122), *σ* (132) *Q* (142); again *m* (110), *t* (231), *w* (121), *σ* (132), *ε* (011); again *l* (120), *x* (131), *Q* (142), *e* (011) and others.

It is not thought worth while to give all the measurements by which the planes were determined, since a greater accuracy than 30′ or 1° could in few cases be attained. For example, in the brachydome zone we obtained: $c\alpha = 8°$, $c\beta = 10°\frac{1}{2}$, $c\gamma = 15°\frac{1}{2}$, $c\delta = 21°$, $c\varepsilon = 29°$, $c\zeta = 39°$, $c\eta = 47°\ 41\frac{1}{2}'$, $c\vartheta = 59°$, $cx = 65°\ 30'$, $c\lambda = 70°$, $c\mu = 73°$–$74°$.

The important calculated angles for the planes observed are given in the following table:

		a, 100	*b*, 010	*c*, 001
g,	410	8° 9′	81° 51′	90°
h,	310	10° 48′	79° 12′	90°
i,	210	15° 58′	74° 2′	90°
j,	320	20° 53′	69° 7′	90°
m,	110	29° 47′	60° 13′	90°
k,	230	40° 39′	49° 21′	90°
l,	120	48° 52′	41° 8′	90°
n,	130	59° 47′	30° 13′	90°
o,	140	66° 24½′	23° 35½′	90°
π,	150	70° 44½′	19° 15½′	90°
p,	160	73° 46′	16° 14′	90°
q,	1·12·0	81° 43′	8° 17′	90°
d,	102	64° 23′	90°	25° 37′
e,	101	46° 12′	90°	43° 48′
f,	201	27° 32′	90°	62° 28′
α,	014	90°	82° 11′	7° 49′
β,	013	90°	79° 38′	10° 22′
γ,	012	90°	74° 39′	15° 21′
δ,	023	90°	69° 54′	20° 6′
ε,	011	90°	61° 14′	28° 46′
ζ,	032	90°	50° 32′	39° 28′
η,	021	90°	42° 19½′	*47° 40½′
ϑ,	031	90°	31° 16′	58° 44′
κ,	041	90°	24° 29′	65° 31′
λ,	051	90°	20° 1′	69° 59′
μ,	061	90°	16° 53′	73° 7′

		a, 100	*b*, 010	*c*, 001
ψ,	112	65° 11′	76° 6′	28° 55′
v,	111	49° 57′	68° 23′	*47° 51½′
s,	221	37° 45′	63° 5′	65° 39′
Δ,	331	33° 49′	61° 36′	73° 13′
R,	411	16° 34′	82° 7′	75° 32′
u,	212	47° 14′	78° 48′	44° 56′
r,	211	30° 44½′	75° 46′	63° 23′
T,	421	21° 10′	74° 31′	75° 46′
ϕ,	232	53° 29′	59° 16½′	51° 39′
t,	231	45° 8′	52° 43′	68° 25′
ρ,	123	73° 17′	70° 47′	25° 55′
χ,	122	67° 12′	63° 40′	36° 5′
w,	121	57° 9′	51° 36′	55° 33′
σ,	132	69° 41′	53° 24′	43° 37′
x,	131	63° 32′	40° 4′	62° 19′
Q,	142	72° 6′	45° 17′	50° 9′
y,	141	68° 19′	32° 15′	67° 21′
z,	151	71° 50′	26° 47′	71° 1′
τ,	163	77° 51′	43° 45′	43° 50′
ω,	161	74° 26′	22° 49′	73° 45′

Twins.—The existence of contact twins with *m* (110) as the twinning plane has already been noted. These have $a\underline{a}=120°\ 25'$, measured 120° 22′, also $b\underline{b}=59°\ 35'$. These twins are common and lead to many interesting variations in the form. A basal projection of one twin is given in figure 5. Repeated twinning is not uncommon; in several cases a large crystal mass was observed having its edge formed of highly modified partial crystals in successive twinning position; some of these suggest crystals of bournonite in aspect. In a single case a part of a stellate form was noted which is idealized in fig. 7. It was too imperfect to allow of determining the exact method of grouping, but the presence of a six-rayed star was clear. These twins are remarkable among similar pseudohexagonal forms because the variation from the required 60° is so small.*

General physical characters.—The cleavages already noted are: highly perfect parallel to *c*; less perfect and interrupted parallel to *a*; still less distinct parallel to *n* (130), and faintly indicated parallel to *b*. The fracture is very perfect conchoidal, yielding lustrous surfaces suggestive of glassy quartz.

* In the preliminary notice mention was made of an apparent penetration twin with a pyramid, inclined on *c* nearly 60°, as twinning plane. The exact measured angle $c\underline{c}$ is 61° 40′, giving as the angle of the supposed twinning plane on *c* either 59° 10′ or 30° 50′; as these do not correspond to any occurring pyramid, the occurrence is probably accidental.

Hardness 5·5–6. Specific gravity=2·845. Luster vitreous and brilliant, but on a natural basal face (*c*) sometimes pearly. Colorless to white or slightly yellowish when not perfectly clear. Transparent.

Optical characters.—The axes of elasticity coincide in position with the crystallographic axes. The axial plane is parallel to *a* and the acute bisectrix normal to *c*, so that a cleavage fragment shows the axes on the border of the field of the polariscope. The dispersion is small, $\rho < v$. The double refraction is negative, in other words *a* is the bisectrix. Sections* cut normal to the bisectrices gave the following for the axial angles:

	Red (Li)	Yellow (Na)	Green (Tl)
2 E	120° 26′	121° 1′	121° 24′

Also

$2\,H_a$	72° 35′	72° 47′	73° 01′
$2\,H_o$	125° 13′	124° 59′	124° 30′

Also $2V_y = 67° 34′$.

A prism afforded by a crystal whose edge was parallel to the axis $\breve{a}$ and whose faces were formed by the planes δ (023) gave tolerable values of two of the refractive indices; the faces, however, were not quite smooth, so that no very high degree of accuracy can be claimed for them. The results for yellow (Na) are: $\beta = 1·5580$, and $\gamma = 1·5630$. Another prism was obtained having the same edge but the faces did not make quite equal angles, as was intended, with the axis $\bar{b}$, which should have bisected the prismatic edge; the values of β are, therefore, fairly good, while those of γ are somewhat too small. Another prism with an edge just parallel to the axis $\dot{c}$ gave good values of the index *a*.

	Red (Li)	Yellow (Na)	Green (Tl)
a	1·5492	1·5520	1·5544
β	1·5550	1·5579	1·5604
γ	1·5604	1·5608	1·5636

It will be seen from these results that the refractive power of the mineral is not especially high, varying but little from that of quartz, which has $\omega = 1·5442$, $\epsilon = 1·5533$ for Na.

Etchings.—It has already been remarked that the crystalline faces are almost always dull, and in some cases show natural etching figures as the result of the action of some solvent upon them. These figures have often great regularity and beauty

* The sections and optical preparations used in our work were made for us very satisfactorily by Mr. H. Hensoldt, School of Mines, Columbia College, New York City.

and merit a more detailed study than our limited time has permitted us to give them. They are most distinct on the basal plane, where they appear as nearly square depressions closely crowded together, at first sight suggesting tetragonal symmetry. Figure 12 will give some idea of the appearance of a portion of the surface; in some cases these pittings run across the basal face in diagonal lines. A more careful examination shows that while square or nearly so in outline the symmetry is rhombic. The little pits are bounded within by two surfaces in the zone *bc*, making an angle of 22° with each other, and in the zone *ac* the prominent surfaces are inclined about 11°, while occasionally other deeper faces inclined 21° are also noted. The angles can be only roughly measured, but they suggest 013(β) and 1·0·10, 105 as probable symbols for the faces in question. The planes in the two series of domes also show at times distinct etching figures, especially *e* (101) and ε (011), but the form is less distinct, though in general acute trowel-shaped with the vertex pointed upward. In some cases those on ε appear to vary slightly from the symmetry about the plane of the axes $\bar{b}\,c$ which the crystallographic relations of the form demands. The *b* faces often show longitudinal figures ($\parallel c$) and others transverse, but their form is not distinct; this is also true to some extent of the prismatic faces. The other planes are almost always slightly roughened, but distinct figures are not often to be made out. Not infrequently the solvent action on the crystals has gone so far as to leave only rounded angles with indistinct planes.

Inclusions.—Another interesting feature of this mineral is the presence of great numbers of fluid inclusions. A superficial examination shows the common existence of a columnar structure normal to the cleavage plane. This is seen in thin sections to be due to great numbers of slender canals parallel to the vertical axis. In some cases these seem to be hollow or filled with earthy matter, but in others they appear as fluid cavities with long bubbles. These vertical canals and fluid cavities are often thickly crowded together, sometimes extending from base to base and again starting from a sharply defined plane within the crystal parallel to the base. The forms of some of these are shown in fig. 9 (×90). Not infrequently, instead of a long cavity, we have a line of them present all lying in the same direction. Besides these regular cavities there are also groups of fine parallel or wavy lines inclined sharply to *c* and giving rise to a peculiar sheen; these are probably also hollow canals.

There are, further, multitudes of other fluid cavities, often so small as to require a high power of the microscope, either

crowded together on an irregular wavy surface passing through a crystal after the manner so common in smoky quartz, or again more or less regularly orientated, parallel to the vertical axis or inclined to it in lines of 45° or 30°. The last becomes a V-shaped arrangement of the minute inclusions in some restricted areas, as is shown in figure 10. Figure 13 shows the usual arrangement and common forms of the cavities (×90). As a rule these cavities, even the smallest, contain each its own bubble, and very frequently two bubbles are noted (cf. fig. 11) often of nearly the same size. This fact, the disappearance of the second bubble with slight rise in temperature, and further the presence or absence of a broad dark rim to the bubble show the nature of the liquids and gases present. In many of the cases we have water with liquid carbon dioxide, and frequently also within this carbon dioxide gas. Occasionally the bubble appears to be air in water, and more rarely the cavity is partially filled with a liquid (CO_2) which does not wet its sides. Solid inclusions, sometimes macroscopic, are also noted.

Chemical examination.—Qualitative tests showed that the mineral is slowly but completely soluble in acids; that it is an anhydrous phosphate of sodium and beryllium containing no other acids and bases, and especially careful tests proved the absence of fluorine, aluminum, potassium and lithium. Before the blowpipe it decrepitates and fuses about 3 to a somewhat clouded glass, coloring the flame deep yellow with a tinge of green on the lower edge.

A quantitative analysis gave the following results:

	I.	II.	III.	IV.	V.	VI.	Mean.	Ratio.	Calculated for $NaBePO_4$.
P_2O_5,	56·09	55·66	55·84	----	----	----	55·86÷142·=·392=1·		55·82
BeO,	----	19·87	19·85	19·81	----	----	19·84÷25·2=·787=2·		19·81
Na_2O,	----	----	----	----	23·68	23·59	23·64÷62· =·381=1·		24·37
Ign.,	----	0·07	0·09	----	----	----	0·08		----
							99·42		100·00

It is evident from this analysis that the mineral has the composition represented by the formula $Na_2O \cdot 2BeO \cdot P_2O_5$ or $NaBePO_4$.

Method of analysis.—In I the P_2O_5 was determined by the molybdic method in a sample of about 0·5 gr. The other five samples were of about 1 gram each. In II, III and IV the substance was fused with Na_2CO_3 and, after treating the mass with water, the BeO was filtered off and weighed, while in II and III the P_2O_5 in the filtrates was determined by the usual method.* A trace of P_2O_5 amounting to 0·17 per cent re-

* This method for separating BeO and P_2O_5 was used by Penfield and Harper in their analysis of herderite: this Journal III, vol. xxxii, p. 107.

mained in the BeO of III, which was carefully determined by the molybdic method and a correction made for it. The purity of the weighed BeO was shown by dissolving that obtained from II in HCl, evaporating off the excess of acid, dissolving the residue in the least possible amount of pure NaOH solution and precipitating the BeO by diluting largely and boiling; the BeO obtained in this way amounted to 19·81 per cent, an amount practically identical with the original weight.

For the determination of Na_2O in V and VI the mineral was dissolved in HCl, P_2O_5 and BeO were separated by the usual methods and the metal was weighed as chloride; the results are probably about 0·7 per cent too low on account of the difficulty of washing some of the precipitates.

Relations to other species.—As has been shown above, the general formula of beryllonite is analogous to that of triphylite and lithiophilite, viz:

Beryllonite.	Triphylite-Lithiophilite.
$NaBePO_4$	$Li(Fe,Mn)PO_4$.

There does not appear, however, to be as close a relation between the forms as might be expected, although our knowledge of triphylite* in this respect is scanty. The two minerals are alike in having two pinacoidal cleavages, but the third prismatic cleavage of triphylite has an angle of about 47°. The vertical axes, however, are nearly equal. The axial ratios are

Triphylite....$\breve{a} : \bar{b} : \dot{c} = 0{\cdot}4348 : 1 : 0{\cdot}5266$ $\quad 001 \wedge 011 = 27° 46'$

Beryllonite...$\breve{a} : \bar{b} : \dot{c} = 0{\cdot}5724 : 1 : 0{\cdot}5490$ $\quad 001 \wedge 011 = 28° 46'$

The optical relations† are different except as regards the size of the axial angle, for which we have $2H_{a,r} = 74° 45'$ triphylite and 72° 35′ beryllonite.

A closer relation seems to exist to the only other phosphate in which beryllium is known to exist, that is herderite. This has the composition $(CaF)BePO_4$ in which the univalent group CaF (partly replaced by CaOH) corresponds to the sodium of the beryllonite. In form the two minerals are apparently related.

Thus we have

Herderite.	Beryllonite.
$110 \wedge 1\bar{1}0 = 63° 39'$	$110 \wedge 1\bar{1}0 = 59° 34'$
$001 \wedge 011 = 22° 57'$	$001 \wedge 023 = 20° 61'$
$001 \wedge 031 = 51° 43'$	$001 \wedge 021 = 47° 41'$
$001 \wedge 331 = 67° 27'$	$001 \wedge 221 = 65° 39'$
$001 \wedge 362 = 58° 30'$	$001 \wedge 121 = 55° 33'$

* Cf. Tschermak, Ber. Ak. Wien, xlvii, 282, 1863, and J. D. Dana, this Journal, II, xi, 100, 1851.

† Cf. Brush and Dana, this Journal, xvi, 118, 1878.

Also

Herderite....$\breve{a} : \overline{b} : \frac{1}{2}\dot{c} = 0{\cdot}6206 : 1 : 0{\cdot}6352$

Beryllonite...$\breve{a} : \overline{b} : \dot{c} = 0{\cdot}5724 : 1 : 0{\cdot}5490$

The optical relations do not correspond very closely except in the size of the axial angle, for which we have in herderite $2H_{a.r} = 72°\ 12'$ Dx. The refractive power of beryllonite is a little lower than that of herderite ($\beta = 1{\cdot}6$). It is certainly most interesting that these two beryllium phosphates should be found within a few miles of each other, and that the same region should have yielded the rare beryllium silicate phenacite.

In conclusion we would express our high appreciation of the liberality of Mr. Sumner Andrews, of Lawrence, Mass., his brother, Mr. Charles G. Andrews, and Mr. Lorin Merrill who have placed in our hands all the best material for study of this rare and beautiful mineral. Without this it would not have been possible to have made our investigation with the completeness that the interest of the subject has made it merit.

ART. III.—*The Iron Ores of the Penokee-Gogebic Series of Michigan and Wisconsin;* by C. R. VAN HISE. With Plate II.

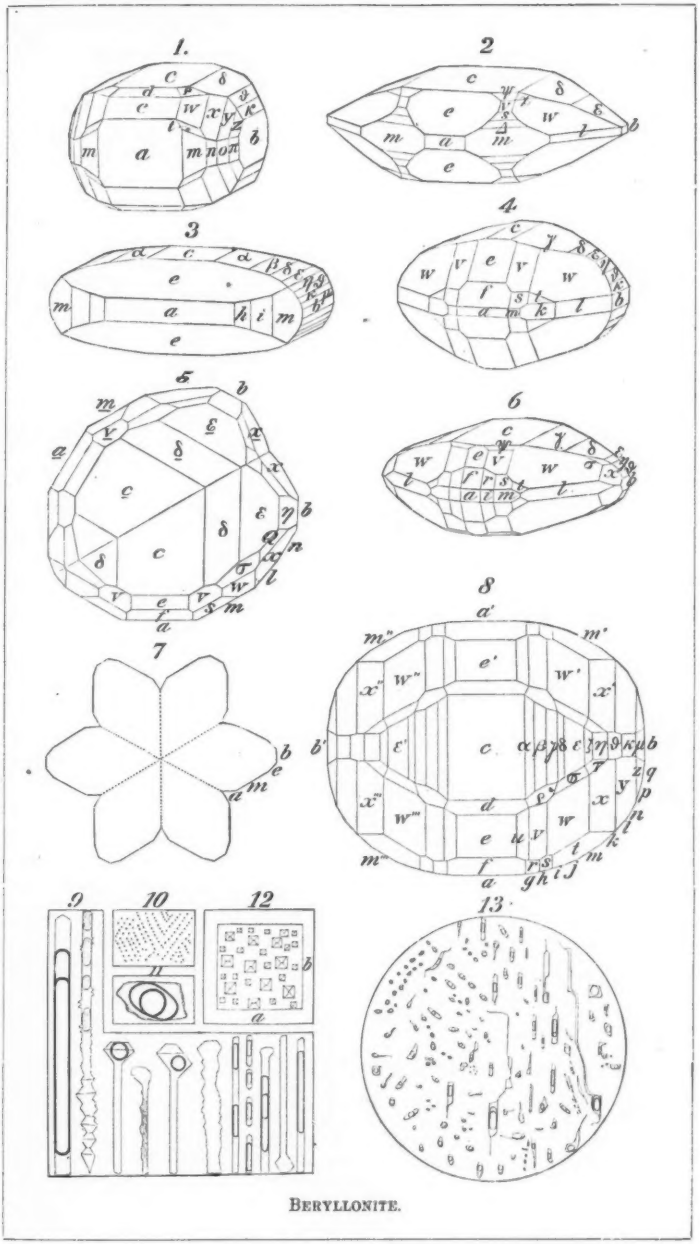
[Published by permission of the Director of the U. S. Geol. Survey.]

THE Penokee-Gogebic Series runs nearly continuously from the vicinity of Numakagon Lake, T. 44 N., R. 6 W., Wis., to Gogebic Lake, T. 47 N., R. 42 W., Mich., a distance of more than 80 miles. The west part of this belt was first fully described by Professor R. D. Irving, and Mr. Charles E. Wright.* A general account of the Range has been given by President Chamberlin.† Other papers have also been published in this Journal, which have from various standpoints treated particular questions in reference to this region.‡ It will, however, be necessary here to give very briefly its struct-

* Geology of Wisconsin, vol. iii, 1880, Part III, pp. 100–167, The Huronian System, by R. D. Irving; Part IV, pp. 239–301, The Huronian Series west of Penokee Gap, by C. E. Wright.

† Geology of Wisconsin, vol. i, 1883, pp. 80–94, The Huronian Age, by T. C. Chamberlin.

‡ This Journal, III, vol. xxix, pp. 237–245, Divisibility of the Archæan in the Northwest, by R. D. Irving. Vol xxxi, pp. 453–459, Upon the Origin of the mica-schists and black mica-slates of the Penokee-Gogebic iron-bearing series; by C. R. Van Hise. Vol. xxxii, pp. 263–265, Origin of the ferruginous schists and iron ores of the Lake Superior region, by R. D. Irving; Vol. xxxiv, pp. 257–259, Is there a Huronian Group? by R. D. Irving.



BERYLLONITE.

ure as a whole before considering the subject of this paper. The series of rocks runs across the country in an approximately east and west direction, the general trend being somewhat north of east. It is a simple series, which has been tilted to the north at an angle of from 60° to 80°. It contains no subordinate folds, and thus the succession of belts is easily made out; one following above the other in perfect conformity. The series rests upon a complex of granite, gneiss, and various green schists. It is overlain by the eruptives of the Keweenaw Series. In our new mapping it will be divided into four belts (see fig. 1), the principle of division being a fragmental or non-fragmental character. At the base of the series is a cherty limestone-member which, in one place, is as much as 300 feet thick, and which varies from this to disappearance. The second member is a feldspathic quartz-slate. On the average it is from 300 to 400 feet thick, and is composed of green, red and brown fragmental slates which contain a good deal of clayey matter. The upper part of this fragmental member is a pure vitreous quartzite, the induration of which has been due to the enlargement of the quartz-grains originally deposited as a sandstone.* The third member of the series is a belt of non-fragmental sediments, about 800 feet thick, which is known as the iron-bearing member from the fact that all the known ore-bodies and heavily ferruginous rocks occur within it. The uppermost member of the series is a thick layer of greywackes, greywacke-slates, and mica-schists and slates. This member is several times as thick as the three lower combined, but in its essential fragmental character it is to be considered as a unit in the series.

The origin of the ferruginous rocks and ores of the iron-bearing member has been considered in a general way in a paper by Professor Irving already referred to. The fundamental conclusion of that paper has been borne out by our later investigations, i. e. that the original rock of the iron-bearing formation is a cherty iron carbonate,† from which the various phases of rock and the ore found in it have been produced by a complex series of alterations.

The principal phases of rock in that part of the formation in which the ore-deposits occur, aside from the cherty carbonate, are heavily ferruginous regularly banded slates, brecciated and concretionary ferruginous cherts, and the ore-

* Bull. U. S. Geol. Survey, No. 8. Upon the Secondary Enlargement of Mineral Fragments in Certain Rocks; by R. D. Irving and C. R. Van Hise.

† The origin of this cherty iron carbonate is a question of great interest, but one which it would take an article of some length to discuss, so this rock is taken as a starting point.

bodies. The carbonate has proved to be far more abundant than was supposed when the paper alluded to was written, and is found at all horizons, but most plentifully in the upper ones. The regularly bedded ferruginous slates are prevalent in the middle, and the ore bodies and ferruginous cherts at the lower horizons. In this paper I have not space to add anything further to what Professor Irving has said as to the particular processes by which the different phases of rock, aside from the ores, have been produced.

Position of the ore in the iron-bearing member.—The iron-ores are all located, as far as known at present, in that part of the iron-bearing formation between Sec. 33, T. 45 N., R. 1 W., Wis., and the east line of T. 47 N., R. 45 W., Mich., a distance of about 30 miles. The greater number of the larger deposits are found in the central half of this area. Also most of the known deposits lie at the base, or very near the base of the iron-bearing member; that is, they rest upon or close to the coarse-grained fragmental quartzite which constitutes the uppermost horizon of the quartz-slates. The number of important mines is about 23, and of these all have deposits upon the fragmental quartzite except five, and three of these, situated east of Sunday Lake, at the eastern extremity of the belt of mines, have exceptional characteristics which exclude them from the present discussion. It is true that three other mines have also deposits which are north of the fragmental quartzite; but in one case, that of the Colby Mine (fig. 4), the two ore-bodies have been shown by developments to have such connections as to show that they are essentially a single deposit. It is not meant to imply that the numerous deposits resting upon the foot-wall quartzite have clean ore always in contact with it. Quite often there is a layer of what the miners denominate "paint rock," or a layer of sand rock between the quartzite and the ore. This latter material is sometimes as much as 20 feet in thickness, although it is usually not more than a few inches, or at most a few feet. Sometimes also there is, between the ore and the quartzite, a mass of greater or less thickness of the ferruginous chert or mixed ore of the miners; rarely a thin layer of nearly pure white chert is found between the ore and quartzite. Notwithstanding these exceptions, the south side of the ore never penetrates the quartzite and in a general way follows it, so that it may be spoken of as resting upon it. This quartzite, although subject to local variations, has an average dip to the north of 60° to 70°, and thus furnishes an approximately regular wall, north of which the ore lies, and is consequently called the foot-wall by the miners. The few deposits north of the foot-wall quartzite are described by Mr. J. Parke Channing as also having regular south walls

which dip with the formation and are known as foot-walls. Whether the ore-deposits rest upon the fragmental quartzite or are north of it, they have then as their southern boundaries a plane dipping to the north at an angle of 60° to 70°.

Dykes in the iron-bearing member.—Mining developments have shown that the iron-bearing member is cut by numerous greenstones, the presence of which would not have been suspected from natural exposures. These greenstones are much altered; many of them are so decomposed as to be soft friable matter which can be picked to pieces with the fingers, and which now contain none of the original minerals which compose ordinary basic eruptives. They retain, however, distinctly their diabasic structure, and occasionally can be traced into comparatively unaltered phases which are true diorites. These altered greenstones are known to the miners, either as soapstones, or as diorite dykes. That they are dykes is manifest from their shape, and the way in which they cut across the layers of the iron-bearing member being traced at times into the foot-wall quartzite. This dyke-like character is well shown by figs. 2 to 7. The association of the ores and these soapstones was found to be so constant, that Mr. J. Parke Channing, Inspector of Mines for Gogebic County, Mich., was secured to work out the relation of the ore-bodies and dyke-rocks. What follows as to the position of the dykes themselves, and as to the position of the ore-bodies with reference to them, is wholly the result of data furnished by his investigations.

The position of the dykes is given with reference to the iron formation in which they occur. This formation has a northern dip and a general east and west strike. As used in reference to the dykes, an east and west direction means parallel with the iron formation, a north and south direction transverse to it. The important thing for the present purpose, is not the absolute direction in which the dykes run, but their relations to the containing formations. The dykes vary a good deal in their dip and strike in different mines, and the same dyke at times in the same mine also varies in dip and strike. However, certain of their elements are quite constant. The dykes always dip to the south, and generally the southern dip, or its component transverse to the formation, is from 20° to 30°. The northern dip of the iron formation has been said to be from 60° to 70°. *It follows from this, that if the stratified rocks were placed again in a horizontal position, the dykes would be vertical.* The true dip of the dykes is usually, however, not exactly transverse to the formation, but east of it; so that a component along the dykes, parallel to the strike of the rocks, has usually an eastern pitch (figs. 2 and 5). This pitch

may be as high as 35°. From this amount it varies to horizontality, or even to a western pitch of 10°. The position of these dykes with reference to the foot-wall quartzite will be better understood by figs. 2 to 8.

The thickness of the dykes varies greatly, running from those of but a few inches in thickness, to those nearly 90 feet thick, fig. 4. In most of the mines in which the ore-deposits are of any magnitude the dykes are six feet or more in thickness; while it is noticeable that the three largest mines have dykes of considerable thickness. At least one dyke has been found in connection with every deposit west of Sunday Lake, with the single exception of the Ironton-Puritan ore-body, and it is possible that when the workings of these mines penetrate deeper they will come in contact with a dyke—one is known to come to the surface three or four hundred feet west. As to the three mines east of Sunday Lake, it has already been noted that their character is quite exceptional. From the eastern pitch of the dykes, it is evident that they must, if they continue in their observed directions, reach the surface to the west of the present workings of each of the mines. As these workings are but a few hundred feet deep, it follows that when these dips are high the dykes would reach the surface but a short distance from the ore-deposits. It thus becomes probable that there are as many dykes in the lower horizon of the iron-bearing member as are seen in all of the different mines, while doubtless there are many more. In some mines there are as many as three or four parallel dykes. In those cases in which there are several dykes in a single mine, one is generally known as the main dyke. The smaller ones are in some cases clearly offshoots from the larger, the actual connections between them being traced.

Position of the ore in reference to the dykes.—The ore has been spoken of as resting upon the fragmental quartzite as a foot-wall, and in exceptional cases as resting upon a non-fragmental quartz-rock, which belongs in the iron-bearing member, but which nevertheless forms a foot-wall for the ore deposits, dipping north with the formation. From the description of the position of the dykes and the quartzites, it is evident that the two rocks form V-shaped troughs, which have at the apices right angles, and the south arms of which are nearer vertical than the north arms; the first being upon an average 20° to 30° from a vertical, while the second is from 20° to 30° from a horizontal position. The relation is that of a right angled trough tilted toward the north until it lacks 20° to 30° from having its arms in horizontal and vertical positions. In one or two mines, for a short distance, these troughs do not incline either east or west, but at most of them, from what has gone before,

it is evident they incline to the east. *The ore-bodies lie in the apices of these roughly shaped troughs*, figs. 3, 4, 7. Each deposit of ore in following a trough will evidently be at different depths at different places east and west, depending upon the nearness of the dykes to the surface. All ore-deposits in the position described would reach the surface if the underlying dykes dip to the east or to the west. As a matter of fact, many of them were found at the rock-surface, but others were found after cutting an overlying rock. However, at present (October, 1888), mining developments have traced all deposits which are large enough to warrant working, with two exceptions, to the surface, and these exceptions are newly discovered deposits, which in all probability will be traced to the surface in the future. As would be expected, it is also true that the development of the deposits which were originally found at the surface have carried them, in every case in which they are of any magnitude, below the surface of the country rock. Both of these facts, the tracing of the ore-deposits discovered at depth to the surface, and those discovered at surface beneath rock, are inevitable deductions from what has preceded.

Rock above the ore.—The rocks which are found above the ore-deposits are the ferruginous cherts—the rocks which have been spoken of as the characteristic ones near the base of the iron-bearing member throughout the area in which the ores occur. The upper boundary of the deposits differs from the quartzite and dyke-boundaries, in that the change from ore to the cherty rock is a transition instead of an abrupt one. In passing upward through an ore-deposit, as its border is reached, the ore becomes mixed with chert until so poor in iron as to become unsalable. In passing still farther upward, the amount of chert becomes greater, until a fractured chert and iron ore, known to the miners as "mixed ore," is found. In passing up still farther this mixed ore grades into the ordinary ferruginous chert of the lower horizons.

To summarize then, the boundaries of the ore-deposits are to the south, either fragmental quartzite or ferruginous quartz-rock in the ore-formation—generally the former; under the ore, the dyke rocks; and above the ore, the typical ferruginous cherts of the region.*

The horizon above the ferruginous cherts, is in most cases a regularly banded red ferruginous slate. This slate is composed of chert and iron peroxide and is as regularly bedded as the unaltered carbonates. Above this slate, constituting the upper horizon of the ore formation, are often found cherty iron carbonates. While this section is known to occur at several of

* Evident practical deductions for carrying on prospecting and mining follow from the foregoing, but in this paper my space is too limited to give them.

the more important mines, it cannot certainly be said to be common to all of them. Also the respective thicknesses of the ill-defined belts are very different at different mines. A general statement may be made, that at most of the mines a cross section of the iron formation shows the proportion of unaltered iron carbonate to increase in passing from lower to higher horizons. It is true that almost solid carbonate occurs at three places at relatively low horizons, although none of them are known to be at the base of the member, while one is certainly underlain by a ferruginous chert Also at several localities a typical chert is found at very high horizons. Figs. 2 to 8 illustrate as wide variations of the relations of the ore-bodies to the surrounding rocks as is anywhere found; yet all are alike in essential points.

Character of the ore.—The iron ore is a soft, red, somewhat hydrated hematite. By chemical analyses it is shown to be more or less manganiferous, the manganese occasionally running to a high percentage. Much of it is so friable that it can be broken down with a pick, although as taken from the mines it is compact enough to hold together in tolerably large lumps. These lumps are porous, often more or less nodular, and also often roughly stratiform. The strata conform in a general way to the strike and dip of the formation. Mingled with this soft hematite, in a few mines, is a small quantity of aphanitic steel-blue hematite. The south deposits carry upon an average more manganese than the north deposits, the average in the South Iron King being above 10 per cent, while from the South Colby, ore has been taken which contained as much as 30 per cent metallic manganese.

The Origin of the Ores.

We have before us the character of the iron ores, the shape of the deposits, their relations to the rocks surrounding them, the nature of the rocks of the iron formation above the ore horizon, and the character of the formations above and below that bearing iron. An attempt will now be made to suggest an explanation of the character and location of the ore-bodies.

The shape of the deposits and their relations to the strata of the iron formation are such as to exclude the idea of original sedimentation in place; neither can they be considered as the result of oxidation of iron carbonate in place alone. All of the unaltered iron carbonate now found contains a much larger quantity of silica than the ores, so much as to make them entirely valueless. Also the red banded slates found at the middle horizons give every evidence of being a material which has resulted from the oxidation of the bedded carbonate in place.

Further, the large amount of manganese which the ores, especially the south deposits, contain is greater than that found in any carbonate from which analyses have been made; and the average content of manganese in the ore is much greater than the average of the carbonates. While it is thus true that the ores are not carbonates of iron which have altered in place, it is almost as certainly true that the iron carbonates of the belt have been the source whence the iron oxides for these ores have been derived. The nature of the evidence upon which this statement is based has been suggested; but the conclusion would be much clearer if there were place to give a detailed description of the rocks of the iron formation as a whole.

Since, then, the iron ores cannot be explained by oxidation of carbonate alone in place, and since the carbonate was the source whence they were derived, they are necessarily concentrations of iron oxide, combined perhaps with iron oxide furnished by oxidation of carbonate in place. If this explanation is adopted, however, it is not only necessary to explain the presence of the iron oxide in its peculiar position, but the nature of the whole lower part of the formation. The explanation must account for the great increase in the amount of silica in the lower horizon of the ore formation as compared with the original cherty carbonate; for its almost total absence in the ore; for the concentration of the iron oxide; for the almost complete absence of carbonate of iron at the lower horizons; for the red banded slates and carbonates in the middle horizons; and for the relatively much more abundant unaltered carbonate in the upper horizons.

A particular occurrence of iron ore.—Before attempting to give a general explanation of these facts, it will first be well to refer to one of several occurrences of narrow belts of iron ore in natural exposure. At Sunday Lake outlet, in Sec. 13, T. 47 N., R. 46 W., Mich., the actual transformation from cherty iron carbonate to iron ore is seen in all its phases. In clefts, joints and partings along the bedding of the exposure are narrow seams of hematite. In passing from the seams, the hematite becomes mingled with some chert; going still farther, the chert increases in quantity until a groundmass of silica contains many rhombohedra of iron oxide. The iron oxide then gradually passes into siderite. This siderite is in perfect rhombohedra, and it is evident, in thin section, that the iron oxide adjacent is pseudomorphous after it. The rock has now passed from an ore into a sideritic chert, which is of a light-gray color, aphanitic texture, and breaks with conchoidal fracture. The latter rock is manifestly in its original condition. The processes by which the seams of iron oxide occupied the space once taken by sideritic chert are plain. The iron carbonate has de-

composed in place to iron oxide, the rock becoming a hematitic chert. Along the seams, waters bearing iron in solution have passed. These waters have particle by particle dissolved out the chert and replaced it with iron oxide, and where once was lean sideritic chert is rich ore. A part of the iron oxide is due to the oxidation in place of iron carbonate, but the larger part has come from a greater or less distance there to be deposited. The seams of iron oxide at this point are but a few inches in thickness, but it is probable that the series of changes which have here taken place upon a small scale, will upon a large scale explain the concentration of workable ore-deposits.

Time at which concentration of the main ore-bodies occurred. —It has been stated that the iron belt rocks are much less altered as a whole in the upper horizons, being there composed largely of unaltered cherty carbonate, while the lower horizons contain very little carbonate and are mostly composed of ferruginous chert and iron ore. It follows as a deduction from this succession, that the series of changes which have so completely altered the lower horizons of the formation have occurred subsequently to the uplifting of the series. The alterations can only be explained by the action of percolating waters bearing oxygen, and which therefore came from above. If the layers were horizontal when the changes occurred, the waters passing downward would have altered most that part of the formation nearest the surface. The reverse would be the case if the alteration was subsequent to the tilting, for the upper layers of the member would partially escape the action of percolating waters, as will readily be seen by glancing at figs. 1 and 9, and taking into consideration the nature of the belt of rock above the ore formation. It is a member composed of black and gray clay-slates, greywacke and greywacke-slates, all of which contain a large amount of clay, rocks particularly impervious to water. A rock underlying any great thickness of such a formation in a horizontal position could not be greatly affected by waters from above. However, when the series had been uplifted and eroded, this upper impervious member would have been removed, and the waters would come directly in contact with the lower horizons of the ore formation, while the upper horizons of the belt would still be somewhat protected.

Before going farther, it is necessary to consider the porosity of the rocks which underlie the ore formation. They have been said to be composed of quartzites and feldspathic quartz-slates. Included in the latter are clay-slates; consequently the rocks of this member are also almost impenetrable to percolating waters. The uppermost layer of the member, the quartzite, is not itself a perfect barrier to the passage of water, on account of the joints which are always found in such a brit-

tle rock. These joints do not affect the underlying slates, for these thinly laminated clayey rocks are so flexible that under the slight bowing which they have received, they are scarcely fractured at all.

Process of Concentration.—An attempt will now be made to trace the passage of percolating waters through the inclined layers of the iron formation. Fig. 9 is a section showing the condition of this member at the present time at the surface, and illustrating how this state of affairs was reached. The strata of the formation are now exposed by their dipping at a high angle, 65°, to the north. The whole Penokee-Gogebic series, more than 13,000 feet thick in some places, of which the iron formation is a part, is exposed in the same fashion. Therefore thousands of feet of the iron member have certainly been carried away by erosion. The figure assumes that about 2000 feet have been eroded from this member since it was upturned. It would, however, make no difference with the argument if this erosion occurred during the time of the upturning. The upper part of the figure represents the surface of the iron formation, and a part of the underlying and overlying rocks at some past time. Near the bottom of the figure is the present land surface, showing the succession of rocks from north to south which are now actually found. A transition from unaltered cherty carbonate to completely decomposed carbonate is noted. At the time when the upper supposed land surface was an actual one, the present surface would be but little exposed to the action of percolating water. It could not pass through the slates which overlie the iron formation; neither could it get in through the underlying feldspathic quartz-slates. Therefore, most of the water which at that time was able to reach the present land surface, must have done so by passing down, along and through the layers of the iron formation itself. The dotted broken line represents a perpendicular course which the water would follow were its passage not deflected by the laminated character of the rocks; but there would be a tendency for this water to follow the bedding, so that, entering the iron formation at its uppermost horizon, it would follow an irregular course marked by a broken line and would reach the foot-wall quartzite at the line of the present surface of the country. It is immaterial to the argument whether this line ought to vary farther from the perpendicular than marked or not; for, in any case, nearly the whole of the present surface of the iron formation would escape the percolating waters, or if not this surface, some other yet lower down. It is, however, probable that the lowest horizon would not thus escape until a great depth was reached; for the waters entering the formation, would

steadily work their way to a greater and greater depth along the foot-wall, until such depths were reached as to prevent its farther penetration.

Now, suppose erosion to gradually sweep away the rocks which are between the old surface of the country and the present surface. Beginning at the base of the formation the rocks at the present surface would be more and more exposed to the action of percolating waters, which would in turn affect the middle, and finally the higher layers until its whole width was subject to the agencies of alteration. There is, then, a gradual increase in the time that percolating waters have acted upon the various layers of the formation in passing from south to north. The difference in time to which the highest and lowest layers have been subjected to such action, is at least the length of time that it has taken erosion to remove the thickness of rock between the old surface of the country and the present surface; therefore the slower the erosion is taken to have been, the greater the difference in time.

Next suppose that erosion had continued until the surface of the land is at some intermediate point. In tracing the percolating waters, it is necessary to take into account the deflection to which they would be subjected by its layers, and the impenetrable character of the underlying slates and intersecting dykes. The relative position of the ore-bodies, quartzites and dykes has already been given. The water which fell upon the layers of the iron formation near its base, would readily pass through the rock, it being here already much altered and broken by the long action of water. Passing through these ferruginous cherts, the water would quickly reach a dyke or the fragmental quartzite, and would follow along this barrier, deflected to the north if upon the quartzite, and to the south if upon a dyke, until it reached a trough made by the dyke and quartzite, along which it would follow, traveling toward the east as it penetrated deeper. Such water would be likely to contain oxygen in solution, and would be capable, if it contained alkalies, which might be readily obtained from the alteration of the basic dykes, of taking up a small amount of silica. Other water falling upon higher layers would make its way slowly and with difficulty through these less altered parts, and would oxidize iron carbonate until all oxygen had been extracted from it. This oxidation of a part of the iron carbonate would liberate carbon dioxide, which would be taken into solution and added to the carbon dioxide which the water already contained.* Such

* In this discussion carbonated water is taken as the agent of solution. It is likely enough that organic acids have helped to take the iron carbonate in solution and bear it to the points of precipitation.

water would take into solution unaltered iron carbonate. It would also in its upper course take up what silica it was able to carry. As it penetrated farther and took more carbon dioxide in solution, and consequently also more iron carbonate, it would be less able to carry silica, and would deposit that material as chert in the lower horizons. The water thus traveling on with an increasing amount of iron carbonate, would finally reach a dyke and be deflected toward the foot-wall quartzite. It would follow this dyke until the apex of the trough was reached; here it would mingle with a larger amount of water more directly from the surface bearing oxygen, and therefore capable of oxidizing the iron carbonate. The iron would then be precipitated in the apex of the trough as more or less hydrated sesquioxide of iron.

Upon the other hand, the silica would here be dissolved; for the carbon dioxide solution containing iron carbonate would be greatly diluted by the large amount of water which bore the precipitating agent for the iron, and the resultant abundant dilute solution of carbon dioxide bearing perhaps alkalies with it, would be capable of taking up silica which was either originally present or had been subsequently deposited in the apex of the trough. Such solutions may have furnished the silica which has enlarged the particles of quartz in the foot-wall and thus indurated it. The result of this leaching would be to steadily add iron oxide to and remove the silica from the apices of the trough formed by the quartzite and dyke, and thus to form ore-bodies. At the same time the other parts of the formation would be steadily impoverished in iron content. Much of that which remained disseminated through the formation would have been changed from carbonate to oxide. In its lower part, the silica which was taken into solution in the upper part of the water's course would be precipitated.*

The processes thus outlined would penetrate to deeper parts of the formation as erosion steadily advanced until the present surface of the country is reached, and the ore-bodies thus formed at depth are now found at surface. It follows that a large amount of iron found in the ore-bodies was originally in rock which has been removed by erosion. So far as the deposits are at the surface, all of the iron oxide, except that

* The chemistry of the processes thus outlined assumes the following: that the oxygen of percolating waters is sufficient to oxidize iron carbonate not in solution and set carbon dioxide free; that the resultant carbonated waters are sufficient to take iron carbonate in solution; that if such waters bearing dissolved carbonates are mingled with other waters bearing oxygen, the iron carbonate or a portion of it will be precipitated; that silica may be carried in percolating waters; that carbon dioxide is sufficient to precipitate silica from such solutions; and that a carbon dioxide solution strong enough to precipitate silica, by dilution, may be made so weak in carbon dioxide that it would be capable of taking silica into solution. All of these facts and principles of chemistry are so well known that no discussion of them or reference to authorities is needed.

which came from the oxidation of carbonate in place, must have come from such a source, while it is probable that a large part of the deposits located at considerable depths have been stored from rock which has been broken down and scattered far and wide. These are not so much concentrations of iron oxide which were originally deposited as a carbonate above them, as from the layers which stretched to the southward, but which were subsequently by upturning placed over the ore-bodies. Also the large proportion of silica now found near the surface, and particularly in the southern half of the belt, is probably much greater than was here originally present. The silica of these highly cherty rocks associated with the ores may represent a concentration from many hundreds, or even thousands of feet of rock which have been swept away, just as the ore-bodies are concentrations from the iron carbonates which these same rocks contained. A portion of the silica may have come from the alteration of the dyke-rocks contained in this removed material, but doubtless most of it came from the original cherty carbonate.

The only exceptions of moment to the facts as assumed in the above discussion, are the occurrence of iron ore at a higher horizon than the foot-wall quartzite, and the ore-bodies east of Sunday Lake, which, so far as present developments go, are not known to be associated with dyke-rocks. It has been said that those ore-bodies in the main part of the range which are north of the fragmental quartzite have a well-defined cherty quartz foot-wall of a regular character. In these cases, this quartz-rock has served as the plane which checked the waters in their downward passage before reaching the fragmental quartzite. Here the relation of the ore to the dykes, and its other characters, are the same as when the ore is found upon the fragmental quartzite. It is of interest to note that in one of the largest mines of the region, the Colby, as shown by Fig. 4, the north and south deposits have as their basement the same great dyke, the two ore-bodies being separated merely by a gigantic horse of rock which served as the impervious layer to form the foot-wall of the north deposit. The explanation given of the origin of the ore found upon the fragmental quartzite, applies perfectly to these north deposits with the modifications above indicated. That there are layers of the iron-bearing formation which are not readily pervious, and therefore become basements along which the down-flowing waters passed, is not at all strange. It would be stranger if, in a thickness of water-deposited sediments of 800 feet, there were no layers which, at least for a short distance, were effectual barriers to the passage of percolating waters. The chemistry of the process of concentration of the ore-deposits east of Sunday Lake, in all

probability, is like that of the typical deposits of the range. Their concentration is apparently, however, more nearly analogous to the narrow seams of ore described in the early part of this paper than to the typical deposits. The formation here apparently being cut by no impervious dykes, the waters have not been carried over to the quartzite, thus forming main channels of percolation, but the comparatively small ore-bodies have developed here and there as favorable conditions for concentration occurred.*

The above explanation of the origin of the ore-deposits accords well with the facts of their occurrence, and also with the idea that the iron formation deposits were originally an impure cherty carbonate of iron. It explains perfectly the peculiar position of the ore-bodies with reference to the dykes and the foot-wall quartzite; it explains their presence in a similar position in the few instances in which the deposits are north of the fragmental quartzite; it explains the flat wedge-shaped character of the ore-deposit; it explains the nature of the ore, a soft somewhat hydrated hematite, bearing more or less of manganese; it explains the excess of manganese which the ore carries beyond the amount found in the unaltered carbonates, and its relatively greater abundance in the south deposits; it explains the presence of large quantities of unaltered carbonates in the upper horizons of the iron formation, the gradual lessening of this carbonate in passing to lower horizons, and its absence at the base of the formation; it explains the large percentage of silica contained in the greater part of the lower horizons and the low percentage at the apices of the troughs.

Probable extent in depth of ore-bodies.—This explanation of the origin of the ores may throw some light upon the depth to which the ore-bodies extend. The fact that all of them have been traced to the erosion surface, is favorable, rather than otherwise, to their extending to a considerable depth. The ore-bodies, at the depths now penetrated, must have formed almost wholly before the sweeping away of the rocks of the iron formation above them. They could, then, have received but little of the iron they contain since the end of the Glacial epoch, for erosion was then terminated by the mantle of drift dropped over the region. The deposits, with some degree of probability, may be said to continue to a depth at which the agencies of concentration could effectively work. Whether this distance will be found to be measured in hundreds or thousands of feet, the data at present are too scant to indicate. I am inclined to believe, however, that they may be depended upon to con-

* As bearing upon the truthfulness of the above theory as a whole, it is an interesting fact that the practical miners, in prospecting, eagerly follow underground water channels, hoping that they will lead to ore-deposits.

tinue for a considerable depth. While they may extend in unimpaired richness and magnitude to a depth as great as can be penetrated by workings, it is certain that they do not continue to an indefinite distance. There is also a possibility that the deposits may become poorer than at the surface at comparatively small depths; for it may be that percolating waters, since the termination of the Glacial epoch, have been able to remove from the upper parts of the deposits a small percentage of silica. Such a removal, even to the extent of five per cent, or less, would have an important influence upon the value of the deposits.

Emmons on Ore-deposits.—It is of interest to compare the conclusions reached, to those of Emmons* as to the origin of the silver-lead-deposits of Leadville, Colorado. He finds that the ore did not form in pre-existing cavities, but by a gradual replacement of the rock materials by substances brought in solutions; and also that these solutions did not come up from below, but have reached their "immediate locus" by passing downward through the rocks above. In his discussion upon ore-deposits in general, he maintains that a like origin is much more common than has been believed. It will be seen that my conclusions as to the origin of the iron ore of the Penokee-Gogebic Series, arrived at independently of Mr. Emmons's work, are in exact harmony with his general conclusions.

Iron ores in other parts of the Lake Superior country.—Before closing this paper, some allusions must be made to the nature and origin of the iron ores which are found in other regions in the Lake Superior country. Large deposits of ore are found in rocks remarkably like those of the Penokee-Gogebic series, in the Vermilion Lake, Marquette and Menomonee regions. These ores are associated in almost every mine with a somewhat varying peculiar rock, universally known as soapstone. The connection between the ore and these soapstones is so constant that the appearance of this peculiar greasy altered material is considered as a very favorable indication in prospecting. It is true that the rock which miners denominate soapstone, in different localities has quite different appearances, and frequently schists are called soapstones which have no essential likeness to the material with which the ore is found associated. These so-called soapstones, in the regions referred to, are at times peculiar green banded schists, at other times are compact strongly foliated sericite-schists, and only occasionally do they retain the structure of

* U. S. Geol. Survey; Monograph XII; Geology and Mining Industry of Leadville; Samuel Franklin Emmons, pp. 375–379. Trans. Am. Inst. Min. Eng., vol. xvi, pp. 804–839. Structural Relations of Ore Deposits, S. F. Emmons.

an eruptive rock; but in the few cases of which we have definite knowledge, the manner in which the soapstones cut the adjacent rocks is that of dykes. This is particularly well shown at the large open pits at the Jackson Mine, Negaunee, Michigan, and at the Champion Mine, Champion, Michigan. This same dyke-like character of the peculiar schistose rock at one mine in the Vermilion Lake series is described and figured by Professor Alexander Winchell.* Mr. James R. Thompson, Mining Engineer for the Iron Cliffs' Mining Company, of Negaunee, Michigan, also finds in quite a number of mines in the Marquette region, that the soapstones have a dyke-like character. With most of the soapstones of these regions, the only evidence that they are of eruptive origin is their relations to the rocks which they intersect. They have not been shown in many cases, as in the Penokee-Gogebic region, to have the typical structure of eruptive diabases; but the transition phases between these much altered rocks and the comparatively unaltered massive eruptives have in some instances been found, and it is probable that many of them are altered eruptives. At any rate, the close association between the soapstones and the ores can hardly be accidental, and, taken in connection with what has been given in reference to the Penokee-Gogebic ores, it is very suggestive that they, in some way, and perhaps in a way similar to that in the Penokee-Gogebic region, have influenced the concentration of the iron in the ore-bodies at the places found. To certainly determine the origin of all these "soapstones," and their stratigraphical and other relations to the ore-bodies will require a detailed investigation. It would, however, be an interesting illustration of the uniformity of nature's processes, if such future investigation should show that the iron ores in the otner regions of the Lake Superior country have an origin like those of the Penokee-Gogebic series.

Madison, Wisconsin, October, 1888.

DESCRIPTION OF FIGURES. PLATE II.

FIGURE 1.—Cross-section of the Penokee-Gogebic series at Penokee Gap, showing the relations of this series to the underlying Laurentian and the overlying Keweenaw series. The figure also shows the conformable succession of the four members of the series itself. At this particular place, the quartz-slate member, as compared with the iron-bearing member, is thicker than usual. Scale 1″=4000′.

FIGURE 2.—Elevation of First National mine, looking south. The eastern pitch of the dyke is shown, and the resultant greater depth of the ore in passing to the eastward. Scale 1″=130′.

FIGURE 3.—Cross-section of same mine, looking east. Scale 1″=130′.

* Geol. and Nat. Hist. of Minn.; 15th annual report, pp. 24–25.

FIGURE 4.—Cross-section of Colby Mine through both north and south ore-deposits. The perpendicular line running through the figure is drawn because the two parts of the section are not exactly upon the same plane. They differ from this so slightly, however, that the true relations of the ore-bodies to the surrounding rocks are shown by the combined figure. Scale 1″=210′.

FIGURE 5.—Elevation of Pence Mine, looking north. The eastern pitch of the dyke is again observable. The right-angled trough made by the dyke-rock and quartzite is in this case not filled with ore throughout the whole figure. At the eastern end of the figure after passing through a heavy bed of drift, the ore constitutes the rock surface. Scale 1″=210′.

FIGURES 6, 7 and 8.—Cross-sections of same at No. 1, 2 and Father Hennepin shafts respectively. In figure 8, the shaft has not yet passed through the ore. Scale 1″=210′.

FIGURE 9.—Section designed to show the variation from unaltered carbonate to ferruginous chert and ore-bodies in passing from higher to lower horizons, and to illustrate the manner of ore-concentration: S=Upper Slate, Q=Quartzite, FQ=Feldspathic Quartz-slate. Scale 1″=1230′.

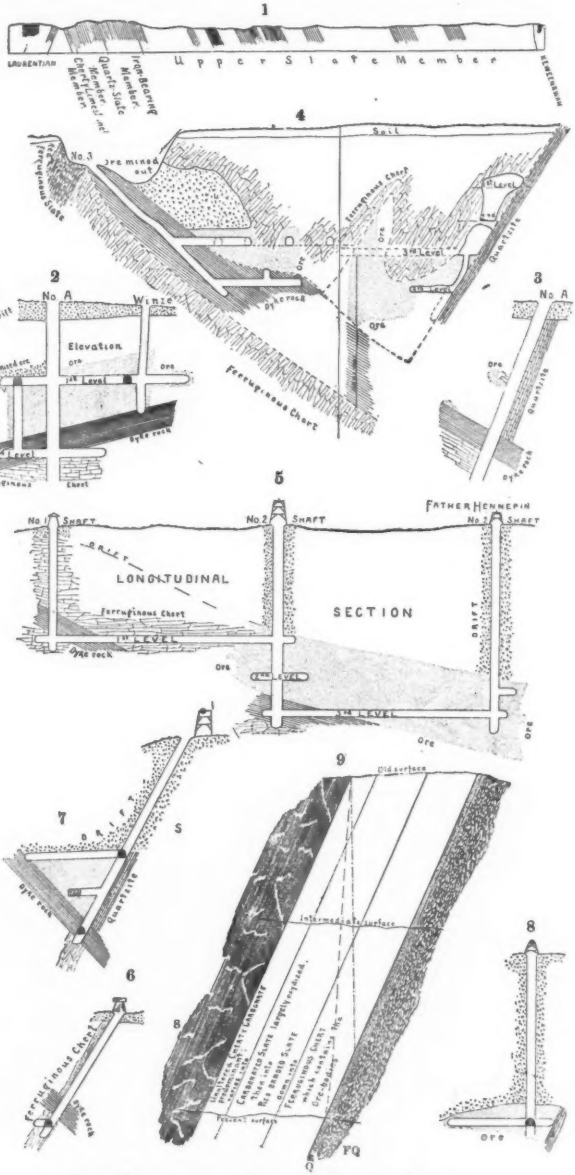
Figures 2 to 8 inclusive are from surveys made and blue-prints furnished by Messrs. J. Parke Channing and C. M. Boss, of Bessemer, Mich.

ART. IV.—*Recent Observations of* MR. FRANK S. DODGE, *of the Hawaiian Government Survey, on Halema'uma'u and its debris-cone;* by JAMES D. DANA.

MR. FRANK S. DODGE has recently made a new survey of Halema'uma'u, the great South Lake basin of Kilauea, which gives definite facts as to the gradual lifting of the debris-cone of the basin, and sustains his conclusions from previous observations that the cone has been floated upward on the column of lavas beneath the floor of the basin.

The accompanying map and the sections 2 to 5, reduced from copy recently received by the writer from him, present the chief results of his survey. In addition I have from him a brief letter of explanations. The scale of the map is 2000 feet to the inch, which makes the distance across the basin from east to west (New Lake not included) a little over 3000 feet. The outline of the debris-cone at base is approximately indicated by the dotted line. The numbers give the level, below the Volcano House datum, of three points at the top of the cone as well as of the floor of the basin and of the crater outside. At *m*, *n*, *o*, *p*, *q*, *r* are small discharging cones, ten to twenty feet high. Two of these small cones, *m* and *n*, were at such a height, owing to the rising of the floor of the basin, that their lava streams overflowed the rim of the basin; and from *o*, the lavas had flowed into New Lake.

Figures 2 to 5 are four profile sections by Mr. Dodge, AB, CD, EF, GH, of the basin and its cone. The height in these sections is exaggerated five times, but in fig. 2, the profile *a b* has the true proportions. In 2 and 3, *p* is the pit within the



IRON ORES OF THE PENOKEE-GOGEBIC REGION.

debris-cone. No attempt to obtain the depth could be made on account of the discharging vapors. The projection above the

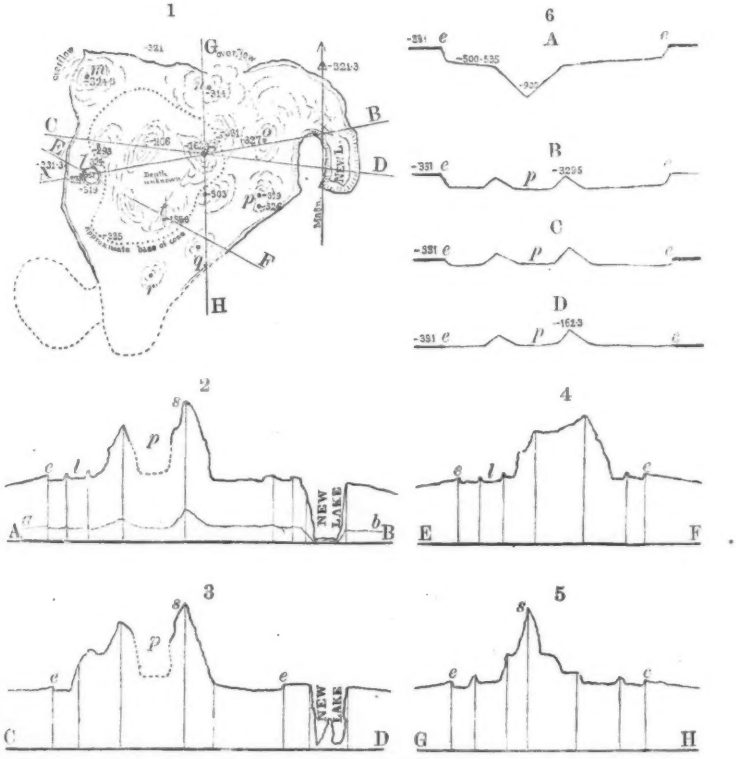


Fig. 1. Map of Halema'uma'a in July, 1888, by Mr. F. S. Dodge, reduced to one-fourth. AB, CD, EF, GH, courses of the sections in Figs. 2 to 5; *m*, *n*, *o*, *p*, *q*, *r*, small cones; *s*, highest summit; *t*, next highest; NEW L., New Lake.

Figs. 2–5. Sections by Mr. Dodge of Halema'uma'u in July, 1888, along the lines AB, CD, EF, GH, vertical scale 400 feet to the inch, horizontal, 2000 feet; *e*, edge of basin of Halema'uma'u; *l*, active lava lake at west foot of debris-cone; *p*, pit in debris-cone; *s*, highest summit of cone.

Fig. 6. Diagram sections of the Halema'uma'u basin and its debris-cone, prepared from the descriptions and maps; *p*, the pit of the cone; *ee*, edges of the basin; A, condition in May, 1886; B, Oct. 1, 1886; C, Aug., 1887; D, July, 1888.

floor of New Lake in fig. 2 is due to the "stranded floating island."

It will be remembered that in April, 1886, a month after the eruption, Mr. J. S. Emerson found the basin 570 feet in depth at middle and 175 to 200 feet deep over a broad border region. The condition is represented approximately (from Mr. Emerson's measurements) in the profile section, A. Three months later, July 20th, Prof. Van Slyke reported that "a cone of loose blocks" had been formed within the basin "perhaps 150 feet high." This is the first notice of the cone.*

In the first week of the following October (1886), less than six months after Mr. Emerson's survey, Mr. Dodge made his first survey. He found the cone standing at the center of the basin, with the "broad border region" around it little changed from the condition observed by Mr. Emerson; but owing to its depth, the top of the cone at *s* was only 2 to 5 feet above the level of the western rim and at *t*, 28·7 feet below the same level. The width of the cone *at top* on an east-and-west line was found to be 1100 feet. The general profile, deduced from the survey, is shown in section B. Ten months later, in August, 1887, the writer found the position of the cone, judging from his estimates, as represented in fig. C. After another eleven months, in July, 1888, Mr. Dodge made his recent survey. The basin was very nearly obliterated, and some parts, as already mentioned, were higher than the level of the rim; as a consequence the debris-cone stood with its whole height emerged. This is illustrated in the fourth of the above sections, D.

From the levels obtained by Mr. Dodge at his two surveys in October, 1886, and July, 1888, and by Mr. Emerson in April, 1888, we have data for determining the rate of change of level. (1) The change in the western rim of Halema'uma'u was nothing; (2) in the summit *s*, 167·2 feet; in the summit *t*, 171·4 feet. The time during which this rise of approximately 170 feet took place was about 650 days, giving for the mean daily rate of rise 3·15 inches.

The small ejections, going on over the basin outside of the cone during the two years past, raised to some extent the level of the floor. But whatever the amount it does not affect the calculation, this being based on changes in the level of the summit, which received no additions from ejections or any other source.

The conclusion of Mr. Dodge that the cone within Halema'uma'u, and the floor of the basin about it had been "floated upward" on the rising lavas appears, therefore, to be the only satisfactory explanation of the change of level.

* Emerson, this J., III, xxxiii, 87; Van Slyke, ibid., 95, 1886.

Art. V.—*Notes on Mauna Loa in July*, 1888.

I. *On an Ascent of Mount Loa by* W. C. Merritt, *President of Oahu College.* From a letter to J. D. Dana, dated July 28.

President Merritt reached the summit of Mt. Loa at noon of the 18th of last July, and encamped near the southeast angle of the crater. The spot was considerably lower than the highest point on the west side of the crater, and probably about 13,400 feet above tide-level. Water boiled at 185° F. between 7^h and 8^h in the morning when the temperature was at 56° F. The thermometer was at 62° F. at noon, 40° F. at 7 P. M., 30° F. at 11 P. M. and 26° F. at daybreak, so that during the night water froze in a large crack, ten feet below the surface. About half a mile south-by-west from the southern end of the crater of Mokuaweoweo (see map, Plate II, vol. xxxvi), there was a small but deep pit-crater. Having descended the east wall of the central pit of Mokuaweoweo to its bottom, a small cinder cone was found not far from the eastern wall; and just southwest, a pumice cone in the midst of an aa flow, the summit of which was very hot and reddish from the action of vapors. In the southwest corner of the pit, there was a cone at F (for all positions see same map), from which vapors were escaping, and south of it, at *m*, a circular pit 300 and 400 feet in diameter by estimate, and 150 to 175 feet deep. The walls of the pit consisted of the edges of layers of basaltic rock one of which was 40 to 50 feet thick, and vertically columnar in structure. The floor of the central pit had, as a whole, a slope from the southwest to the northeast, confirming the view that the southwest part of the pit had been the seat of greatest activity, as it is in Kilauea. Southwest of *m*, the outer wall of the central pit was cut through from top to bottom by two parallel fissures, which had a S.S.W. direction, and thence pointed nearly toward the place of chief eruption of 1887. East of *m* and near the wall in the direction of L, there were great numbers of small fumaroles, from which sulphur vapors were escaping freely, and large deposits of sulphur had been made about them. Near *h* two dikes, 2 to 2½ feet thick, intersected the walls, crossing one another at a small angle, the rock of which had a feldspathic aspect.

From a rough measurement, the depth of the crater on the east side was made not over 350 feet. If this small depth is sustained by careful observations, a great change of level had taken place since the survey of Mr. Alexander in 1885. Such a change might have been among the effects of the eruption of February, 1887.

In Prof. Dana's paper of July last, accounts are cited of a fountain of lavas in the summit crater in 1873—in June, by Mr. W. L. Green and Miss Bird, and in August, by Dr. O. B. Adams. President Merritt obtained from Mr. E. G. Hitchcock the following facts observed by him and Mr. H. R. Hitchcock on a visit to the summit in October, 1873. They spent one night at the summit near the site of Wilkes's camp, on the east side of the central crater or pit. At the time a fountain of lavas was playing in the southwestern end of the crater, to a height of 600 feet. The height was ascertained by lying upon the brink and looking across the pit to the top of the opposite wall; the column of fire ascended at least one-half higher than the distance from the floor to the top of the walls, and taking this distance at 400 feet, the height of the fountain was decided to be approximately 600 feet. Moreover the descending lava of the fountain, falling into the basin, flowed off northward nearly the whole length of the western side of the pit.

President Merritt also visited Kilauea on July the 14th. His letter speaks of the walls of Halema'uma'u as in part wholly obliterated, as represented by Mr. Dodge; it was 15 to 20 feet high in some places. The nearly circular lake (at *l*) on the west side of the cone (which he calls "Dana Lake") was in ebullition, but not more active than in August, 1887. The enclosing walls of this small lake were 10 to 15 feet high above the liquid lava within, and 15 to 20 feet above the floor outside. With regard to the rising of the cone in Halema'uma'u Mr. Merritt expresses full confidence in the view of Mr. Dodge.

II. *Notes on Mount Loa by* Rev. E. P. Baker.

In the month of July, Rev. E. P. Baker of Hilo, made an excursion to the summit of Mt. Loa, and also to the sources of several of its great eruptions, and, in addition, visited the lava stream of Kilauea of 1849 and the Kau "desert." Mr. Merritt's trip to Mokuaweoweo was made with Mr. Baker. The following notes are from a letter on his excursions addressed to the writer. Mr. Baker also made a valuable collection of rock-specimens which will add much of interest to the paper on Hawaiian lavas soon to be published by Prof. E. S. Dana. J. D., D.

To the facts respecting the summit of Mt. Loa, reported by President Merritt, Mr. Baker adds that he observed six parallel fissures ten to twenty rods apart at the south end of Mokuaweoweo which had a course toward the place of eruption of 1887, and which were probably there produced at the first outbreak, before the outflow of the lavas in Kahuku. (See vol. xxxvi, p. 24.) A descent was made into the southern crater of Mokuaweoweo —probably the first ever made—and the depth found to be

seventy-five feet greater than that of the central crater. A fresh-looking lava stream descended into it down the northern wall, which may have been made in 1887.

Mr. Baker, speaking of the source of the lava streams of the great eruption of 1880–81, states that the two streams from the source, the Kau or southern and the Hilo or eastern (see map, Plate I, vol. xxxvi) originated together at the extremity of a long fissure. This fissure follows the course of a "divide," so that a small obstacle was sufficient to turn the flow to one side or the other. The outflow took place on this divide; a northern stream flowed first, then the Kau stream, and then the Hilo. The fissure ran by the north side of Red Hill, a cone with a deep crater which is still giving out vapors, and this hill was apparently the occasion of the turn off southward of the Kau stream, it standing at the point of their divergence. Water boiled near this hill at 196° F. This Kau stream is in general aa, but near the source it is pahoehoe. At the upper extremity of the fissure there is a pit crater, Pukauahi, which is described as the source of the lavas and is still smoking. At this place also water boiled at 196° F.

On the route from Ainapo to the source of the outflow of 1852, the lavas of the 1852 stream, where they were first reached, were of the aa kind; but after awhile there was a change to pahoehoe, and soon after this the source was reached —a red cone in the midst of an extensive bed of pumice. Long ditches or trenches occur in the surface of the region which were evidently the beds of lava streams, their sides having been the banks. The flow appears to have had a single outlet. Water boiled at the source at 200° F.

Going from Ainapo to the source of the eruption of 1887, in Kahuku, about 6000 feet above the sea-level, Mr. Baker passed through regions of woods and grass and saw seven running streams and three or four ponds of water. There had been heavy rains. The fissure of 1887, about 400 feet above the place of outflow, was still giving out vapors. No deep crater marked the place of discharge.

Over the wide region beween Mt. Loa and Mt. Hualalai it is hard to tell where the slope of one ends and that of the other begins. The 1859 flow of Mt. Loa as it came down heading northwestward, turned just enough northward to fetch by the northeastern flank of Hualalai.

The *Kau desert*, lying to the south and southwest of Kilauea, has a surface of whitish or light colored sand with areas of pahoehoe lava, which is decomposing at places into a reddish soil. It is about eight miles by six in area. It is destitute of vegetation and owes its dryness to its being under the lee of Kilauea.

Art. VI.—*A Quartz-Keratophyre from Pigeon Point and Irving's Augite-Syenites;* by W. S. Bayley.

(Published by permission of the Director of the U. S. Geological Survey.)

(I.) Introductory.

One of the most striking features in the geology of Pigeon Point,* Minnesota, is the occurrence there of a bright red rock along the borders of the large mass of olivine-gabbro, which forms the main portion of the point. This rock is best seen along the south or Lake Superior side of the point near its eastern extremity, where its brilliant color when moistened by the water, forms a beautiful contrast to the dark gray of the gabbro with which it is in contact.

The first mention of the rock was made by Dr. Norwood,† Assistant U. S. Geologist, in 1851, who described it as a reddish colored syenitic rock, containing but a small amount of quartz. About thirty years later Professor N. H. Winchell, of the Minnesota State Survey, saw a red rock‡ associated with gabbro near the extremity of Pigeon Point, and a rock§ red with orthoclase, from its north shore about a mile from its eastern extremity, which latter he mentions as having probably originated by the fusion and recrystallization of the sedimentary beds through which the gabbro cuts. A microscopical examination of this rock has very recently been made by Dr. M. E. Wadsworth,‖ who regards it as an altered phase of some eruptive, the original nature of which he is unable to decide from the single section at his command. Professor R. D. Irving¶ in 1881, described a red rock from Brick Island, one of the smaller of the Lucille group of islands, about a mile south of Pigeon Point. He says: "Its thin section reveals a rock very close to those red rocks of the Keweenaw Series which I have described under the names of augite-syenite and granitic porphyry." On Pigeon Point also Professor Irving found a red rock which "resembles in every particular the rock from Brick Island."

Similar red rocks have been observed by several geologists at various other places in the Lake Superior region, but no careful study has been made of any one of them.

* For exact location see this Journal, June, 1888, p. 388.

† Report of a Geological Survey of Wisconsin, Iowa and Minnesota. By D. D. Owen, U. S. Geologist, Philad., 1852, p. 399.

‡ Geol. and Nat. Hist. Survey of Minnesota for 1880, p. 70.

§ Ib. for 1881, p. 57.

‖ Geol. and Nat. Hist. Survey of Minnesota, Bulletin 2. Preliminary Description of the Peridotytes, Gabbros, Diabases, etc., of Minnesota, 1887, p. 81.

¶ Copper Bearing Rocks, etc. Monog. V., U. S. G. S., 1883, p. 369.

(II.) Macroscopical and Microscopical.

The red rock of Pigeon Point presents several phases differing in some respects from one another. In its most typical aspect it is a brick-red, fine grained, drusy rock, speckled with little spots of a dark green color. Scattered through the prevailing red feldspar are small grains of white quartz, which sometimes present well-defined crystal outlines. The feldspar itself is occasionally observed with a well marked cleavage and rarely with a crystal outline. Usually it has no distinctive morphological characteristics. In some cases a small quantity of a light colored feldspar can be detected intermingled with the red variety. The green spots consist of little plates of chloritized mica.

Under the microscope the coarser grained of these non-porphyritic varieties are seen to be composed essentially of an hypidiomorphic granular aggregate of at least two feldspars, quartz and chlorite, with a few subordinate constituents—muscovite, rutile, leucoxene, magnetite, hematite and apatite.

The feldspars embrace a striated plagioclase, twinned according to the Carlsbad law, and in one instance according to the Manebach law, and a second, less well individualized feldspar, which is younger than the plagioclase, but slightly older than the accompanying quartz. It surrounds the plagioclase and is intergrown with the quartz in micro-pegmatitic and granophyric forms. Both the plagioclase and the granophyre feldspar are colored by numerous little plates of hematite, the plagioclase, however, containing fewer of these than the granophyre variety. When the latter occurs with its own outlines, as it occasionally does, it appears to be unstriated, though frequently in Carlsbad twins. After hematite, apatite, leucoxene, and little plates of muscovite or kaolin, are the most common inclusions of both varieties of feldspar. In no case could crystals be found fresh enough to yield measurements of sufficient accuracy to determine their true nature.

The quartz is in irregular areas filling in the interstices between the other constituents, and is also intergrown with red feldspar as has already been described. It contains numerous fluid cavities with little dancing bubbles, and also inclusions of a dust-like substance and little areas of red feldspar.

The chlorite owes its origin principally to a formerly existing biotite. It occurs both in little radiating spherulites crowded close together, and in plates enclosing quartz and feldspar. Calcite, rutile and leucoxene are its most common inclusions, while the little pleochroic halos* (Höfe) characteristic of this mineral when derived from biotite, are not rare.

* For the discussion concerning the nature of these halos, see Neues Jahrb. f. Min., etc., 1888, i, p. 165.

Associated with the chlorite is oftentimes a very light green fibrous mineral, which from its bright polarization colors is probably to be referred to sericite. Rutile forms quite a prominent constituent in some specimens. It is found in irregular masses of a dark brown color, and also in long rod-like forms, in both cases intermingled with leucoxene and frequently with chlorite.

A second phase of the red rock resembles quartz-porphyry. Well terminated quartz crystals and occasional brick-red and greenish-white feldspars are scattered through a very fine grained groundmass of a dark red or purplish color. This variety is characterized under the microscope by the beauty of its granophyre structure. All gradations between the granular structure just described, and the typical porphyritic structure have been examined, and in all there is more or less of the true granophyre. In the most typical porphyritic varieties the porphyritic crystals are both quartz and feldspar. In the less perfectly developed phases the quartz occurs in round, elliptical and even crescent-shaped areas, and includes in many places portions of the groundmass. This quartz is perfectly clear and is free from inclusions other than the little fluid cavities with movable bubbles (see fig. 1.)

A very few irregularly outlined feldspar areas represent the porphyritic crystals of this mineral in their earliest stages of development. They are now so altered as to prevent the identification of their species.

Other areas which appear in the hand specimen as crystals are seen under the microscope to be composed of granophyre substance in which the feldspathic portion is very highly colored by little plates of hematite.

The groundmass, in which these crystals are imbedded, consists of quartz and highly altered feldspathic substance in granophyric intergrowths. This is in part sometimes replaced by coarser areas in which the two minerals form a micropegmatite. The fine granophyre is found more particularly around the distorted and corroded porphyritic quartzes, and in the undeveloped feldspars mentioned above. It radiates from all porphyritic quartzes forming a zone, which in ordinary light resembles the "quartz globulaire" of Lévy, but in which the quartz fibers, between crossed nicols, are seen to be optically independent of the orientation of the substance of the crystals.

Chlorite, iron hydroxides, leucoxene, and tiny flakes of a dark brown biotite are the accessory constituents of the groundmass. Calcite is quite abundant as an alteration product of some of the fibres intergrown with the quartz, and also in the little cavities contained in the rock. Green alteration-products are also common. Fig. 1 is an ideal representation of the most

characteristic peculiarities of the groundmass and its porphyritic ingredients as exhibited by several thin sections.

The microscopical characteristics of both the porphyritic and the granular varieties of this red rock indicate the probability of the identity of the two. Although the most typical quartz-porphyry is quite different in structure from the typical granular variety, all gradations between the two types can be recognized. Their mineralogical composition is the same, and, as will be shown later, their chemical composition is identical. There can be little doubt that the porphyritic variety is a true eruptive rock. It presents all the features of Rosenbusch's* "Vogesen granophyres." Since the granular varieties are so similar to this, it is also probable that these also are eruptive. No trace of fragmental structure could be detected in any one of them, nor is there any field evidence that they are altered fragmentals. All the field relations seem to point to the *original* character of the rocks. They occur in dykes and veins intersecting other rocks, and the contact between them and the quartzites which they cut, is sometimes clearly seen. It must be confessed, however, that without microscopical and chemical evidence of the identity of these rocks with the quartz-porphyry their true nature would be difficult to discover from the field relations alone. A more careful examination of the structure of the point than has thus far been possible, will probably reveal facts which will place beyond doubt the conclusions reached by the microscopical examination.

1.

The quartz-porphyries are very similar in macroscopic and microscopic appearance to the Keweenawan quartz-porphyries described in Irving,† as flows in the copper-bearing rocks on both sides of Lake Superior. The granular red rock approaches more nearly this author's augite-syenites, though the best developed and most characteristic augite-syenites are more nearly allied to the third phase of the red rock. The rock of Brick Island, which is classed by Irving among the augite-syenites agrees in most of its minute features with the rock described above as the most prevalent type of the red rock on Pigeon Point, as Irving‡ himself states.

* Die Steiger Schiefer, etc. Strassburg, 1876.
† Copper-Bearing Rocks, p. 95. ‡ L. c., p. 369.

The third variety was noticed more particularly at the contact with an olivine gabbro, which occurs on the point in larger masses. As the red rock approaches the gabbro it is clearly seen to be affected by the latter in such a way as might be expected if both rocks were in a pasty condition at the same time, or if one had been intruded in or next to the other under enormous pressure. The red rock becomes darker as it approaches the gabbro. The green spots, which are scattered over the red groundmass, become more prominent. They are larger in size and more abundant in number than in the two varieties above described, and in some cases are united into red-like bodies and arborescent forms (fig. 2). A light colored feldspar is also much more frequently discernible in this variety.

2.

Still closer to the gabbro a rock is observed which is very dark in color, and can be distinguished from the gabbro only by the possession of a reddish feldspar among its components. The darkest of these rocks resembles very closely the orthoclase gabbros* of Irving, which are supposed by Dr. Wadsworth† to be but altered forms of olivine-gabbro. A discussion of this point can not be entered upon in this place, but it is hoped soon to obtain results from the work now being carried on, which will determine whether or not the orthoclase gabbros may have been derived by the action of an acid magma upon a basic gabbro with which they are always associated.

The lighter colored of these intermediate rocks (as we shall call them for the sake of brevity) when examined under the microscope are found to differ but little from the red rocks described above. They contain a larger amount of plagioclase (oligoclase ?), of chlorite, and of biotite, and much more magnetite and apatite than do the latter, but otherwise resemble them very closely. Micropegmatite is more frequent than is the granophyre intergrowth of quartz and feldspar, and it is especially to be remarked that in almost every case examined the extinctions of the little quartzes are in the direction of their longer axes. The most noticeable fact in relation to them is the freshness of their plagioclase, which is usually in large tabular or lath-shaped crystals.

When examined carefully and compared with sections of Irving's augite-syenites they are seen to bear a strong resemblance to some of these—a resemblance so strong that pictures‡ representing the augite-syenites might as well be used to illustrate the appearance of the Pigeon Point rocks under the microscope.

* Copper-Bearing Rocks, p. 50.

† L. c., p. 54. Cf. also Herrick et al., American Geologist, June, 1888, p. 340.

‡ Copper-Bearing rocks, p. 112, and figs. 1, 2, 3, 4, Pl. XIV.

After a careful microscopic examination of every one of the thin sections of rocks described by Irving as augite-syenites and a comparison of these with the typical red rock of Pigeon Point and its associated intermediate varieties, the conclusion is established beyond doubt that some of the former are in every respect similar to the typical red rock of the point, while the others are as certainly identical in all essential particulars with those varieties which have been called its intermediate varieties.

(III.) Chemical and General.

From a mere microscopical examination of different sections of the various phases of the red rock on Pigeon Point, one would naturally be lead to regard them as portions of the same magma which had crystallized under different conditions, and then had undergone more or less decomposition. They both possess the same mineralogical composition and present gradation in structure from the granular to the porphyritic, with granophyric groundmass.

In order to obtain more positive evidence on this question, analyses of the quartz-porphyry and also of the granular rock were made by Mr. W. F. Hillebrand in the laboratory of the U. S. Geological Survey, with these results:

I. Analysis of the powder of seven of the freshest specimens of the granular rock.

II. Analysis of the powder of three of the quartz-porphyries.

III. Analyses of the granite from Bejby, Sweden; containing red orthoclase, gray and brownish gray quartz, black mica, and a few flakes of a golden yellow mica.*

	I.	II.	III.
SiO_2	72·42	74·00	73·32
TiO_2	·40	·34	----
Al_2O_3	13·04	12·04	14·25
Fe_2O_3	·68	·78	----
FeO	2·49	2·61	2·60
MnO	·09	·05	·09
CaO	·66	·85	·83
BaO	·15	·12	----
MgO	·58	·42	----
K_2O	4·97	4·33	4·96
Na_2O	3·44	3·47	3·21
Li_2O	tr.	tr.	----
H_2O	1·21	·86	1·22
P_2O_5	·20	·06	----
Cl	tr.	tr.	----
	100·37	99·93	100·48
Sp. Gr.	2·620	2·565	

* Gerhard: Neues Jahrb. f. Min., etc., 1887, ii, p. 271.

After an inspection of these figures there can be no reasonable doubt that the two rocks from Pigeon Point are parts of the same mass. The very slight differences in amount noted in the case of the silica, alumina and potash are not greater than are frequently found in different portions of the same hand specimen of most rocks. The slight difference in specific gravity are what might be expected from a study of the structure of the rocks.

Unfortunately no complete analyses of Irving's Keweenawan quartz-porphyries are given by that geologist, but a few silica determinations have been recorded, which are of interest in showing the close agreement, in this respect, between these rocks of undoubted eruptive origin and the Pigeon Point rock. The percentages of silica in three Minnesota quartz-porphyries* are respectively 71·10, 73·87 and 76·83; thus differing but slightly from the 74 per cent. of the Pigeon Point rock.

In consideration of the large amount of sodium indicated in analysis I, it was thought interesting to separate the feldspar from one of the freshest of the red rocks and subject it to a chemical examination. This was done in the usual way, and it was found that the greater portion fell when the specific gravity of the solution used was 2·577. This was analyzed by Mr. Whitfield of the U. S. Geological Survey with the following result:

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	Ign
65·00	18·22	2·64	1·06	0·06	4·18	8·40	·46=100·12

When examined under the microscope the powder of this mineral is seen to be free from quartz and quite homogeneous, although slightly altered and filled with little plates of hematite. Its optical constants could not be accurately determined, but from the figures given above there can be but little doubt that the feldspar is an anorthoclase.†

If this be true the rock would fall into the quartz-keratophyre group as defined by Rosenbusch.‡ Its microscopical characteristics correspond to those of the quartz-keratophyres, as described by Gümbel and Lossen, and the composition of its feldspar is that of an anorthoclase.

Many of the quartz-porphyries of the Keweenawan series, as well as some of the augite-syenites will probably be found to belong to this same class of rocks—a class which up to the present time has not been known to have a representative on this side of the Atlantic.

One of the most interesting points in the study of the red rocks of Pigeon Point, has reference to the origin of those

* Copper-Bearing Rocks, pp. 108, 109, 100, 441.

† Anorthoclase separated from a liparite of Pantelleria, has a composition (according to Förstner, Zeitschr. f. Kryst., 1883, p. 125) as follows: SiO_2=66·06, Al_2O_3 19·24, Fe_2O_3 0·54, CaO 1·11, MgO 0·11, K_2O 5·45, Na_2O 7·63.

‡ Rosenbusch: Mikroskopische Physiographie, 1887, ii, pp. 434–442.

phases which are found upon the contact with olivine-gabbro. As has already been stated, the macroscopical and microscopical characteristics of these rocks are such as would lead to the supposition that they were produced by the mutual interfusion of the basic and acid rocks at their points of contact. The field relations of the three rocks leave no doubt as to the fact that the intermediate rock is the result of contact action. That this action took place at some distance below the surface is proved by the perfect crystallization of the constituents of the intermediate rock. That it was not confined to the effect of solutions passing from the gabbro to the keratophyre, or the reverse, is shown by the perfect freshness of the plagioclase, and its well-defined crystal outlines in both rocks.

The best place upon the point at which to study these rocks is on its south side, near its eastern extremity. Here the space between the fresh olivine gabbro and the typical quartz-keratophyre is occupied by a series of rocks which exhibit in the field a gradual transition between the heavy, dark basic rock, and the light red keratophyre.

Analyses and specific gravity determinations of several of these intermediate products substantiate the conclusions arrived at above.

IV. Olivine gabbro, analysed by Mr. Hillebrand.
V. Intermediate rock (No. 11211) near the gabbro.
VI. Intermediate rock (No. 11209) midway between the red rock and the gabbro.
VII. Intermediate rock (No. 11210) near the keratophyre, analyzed by Mr. Hillebrand.
VIII. Quartz-keratophyre, as given on p. 59

	IV.	V.	VI.	VII.	VIII.
SiO_2	49·88	50·69	57·88	57·98	72·42
TiO_2	1·19	----	----	1·75	·40
Al_2O_3	18·55	----	----	13·58	13·04
Fe_2O_3	2·06	----	----	3·11	·68
FeO	8·37	----	----	8·68	2·49
MnO	·09	----	----	·13	·09
CaO	9·72	7·94	4·68	2·01	·66
SrO	*tr.*	----	----	*tr.*	----
BaO	·02	----	----	·04	·15
MgO	5·77	----	----	2·87	·58
K_2O	·68	----	----	3·44	4·97
Na_2O	2·59	----	----	3·56	3·44
Li_2O	----	----	----	*tr.*	*tr.*
H_2O	1·04	----	----	2·47	1·21
P_2O_5	·16	----	----	·29	·20
Cl	*tr.*	----	----	----	----
	100·12			99·91	100·33
Sp. Gr.	2·923		2·741		2·620

In these results can be traced the gradual transition from the basic gabbro, rich in calcium and magnesium, and poor in potassium, to the acid keratophyre, which is poor in calcium and magnesium and rich in potassium. We can hardly imagine the conditions under which a rock of the composition of the gabbro (IV) could be changed into a rock of the composition of the intermediate rock (VII), by means of solutions* emanating from the keratophyre, unless these solutions contained in them the materials of the keratophyre in about the proportions in which they are present in that rock, a supposition which is not at all probable.

It would seem, then, that we are justified in regarding the intermediate rock as due to the fusion and recrystallization of the materials of both the keratophyre and the gabbro, in consequence of the irruption of one of these rocks into the other at some considerable depth below the surface of the earth, where the conditions were such as to produce a rock with the characteristics of a plutonic rock. In other words the intermediate rock is the result of deep seated contact action.

Analyses of Irving's augite-syenites are not given, so that a comparison of their composition with that of the intermediate rock (No. 11,209) cannot be made. Their thin sections, however, as has already been stated, exhibit a very close similarity to many of those of the contact rocks. Further, those with these characteristics are always, so far as could be determined, in close association with gabbro, and in many cases are also very near a more acid red rock resembling the quartz-keratophyre in one of its phases.

The augite-syenites of Irving, then, may be divided into two classes, those which are like the quartz-keratophyre, described above, and those which are similar to the contact rock. In neither case are they altered eruptives, in the sense that they owe their present characteristics to the alteration of a more basic eruptive. They have both resulted from the solidification of a molten magma.

Of course it is not affirmed that no alteration has taken place in any of the augite syenites, for such is not the case. Some of them have suffered the kaolinization of their feldspar, and the chloritization of their augite and mica, with the production of secondary silica. Their most characteristic properties, however, are not due to this alteration, but are due to the chemical composition of the magma by whose cooling they were formed.

* Cf. American Geologist, June, 1888. p. 343. Messrs. Herrick, Clarke and Deming: Some American Norites and Gabbros.

(IV.) Conclusions.

The red rock on Pigeon Point is not an altered gabbro nor an altered sedimentary rock, but is the result of the solidification of a magma, which under certain conditions gave rise to a rock with the characteristics of a granophyre. These two rocks contain a sodium-potassium feldspar, and thus should be classed among the quartz-keratophyres.

Upon the contact of the quartz-keratophyre with an olivine-gabbro is a series of rocks, which possess a composition intermediate between those of the keratophyre and the gabbro. They may be regarded as the result of contact action at great depths

Irving's augite-syenites are similar to the Pigeon Point quartz-keratophyre, in some instances, and in others are like the intermediate rocks. They are neither altered gabbros nor altered forms of a previously existing augite-syenite.

Geological Laboratory of Colby University, June 25, 1888.

Art. VII.—*On the occurrence of Hanksite in California;* by Henry G. Hanks.

The best known locality of hanksite in California is Borax Lake, owned by the San Bernardino Borax Company. This lake lies in township twenty-five South, range forty three East, Mount Diablo base and meridian, and in the northwest corner of San Bernardino county, the largest in the state, very near the Inyo county line. This vast deposit of soluble salts was discovered and located February 14, 1873, by Dennis Searles and E. M. Skillings. Up to the present time it has produced 10,500 tons of borax, and is still far from being exhausted. When the state becomes more populous, and facilities for cheaper transportation multiply, other minerals will also be extracted, to the benefit of those interested, as well as to the State.

The so-called "Dry Lake," "Alkali Flat" or "Salt Marsh," is a pan-like depression in the desert, ten miles long and five wide more or less. It is the sink of a wide spread water-shed and a small stream which heads some fifty miles south. It is the opinion of those who have long resided at or near the locality, that it is a secondary sink of Owens Valley and is partly fed by seepage from Owens and Little Lakes. The climate is generally very dry, but during some seasons, considerable water finds its way to this depression. Having no outlet, the water spreads out and forms a shallow lake or marsh. In the dry season the surface is covered with an alkaline incrustation, which is principally common salt. On the

western margin of the large depression lies a small basin known as "Borax lake proper," which has approximate dimensions of one mile and a half in length by half a mile in width. From this secondary lake, and the dividing ridge referred to below, most of the borax produced has been taken.

Between Borax Lake, which is a few feet higher than the general level, and the wide alkali flat, there is a slight ridge, which acts as a natural dam and prevents the water from flowing away. It is covered with crude borax which is believed to be of semi-volcanic or solfataric origin. This barrier prevents the water of the borax lake from flowing to still lower depressions on the great alkali flat beyond. The water of Borax Lake is a dark brown highly concentrated alkaline liquor, having a density of 28 degrees Beaumé. The salts obtained from it by crystallization contain carbonate, chloride and bi-borate of sodium, with much organic matter. There has never been an exhaustive analysis made, which would, no doubt, be very interesting.

For a number of years it was planned to explore or prospect the underlying formations both as a matter of general interest, and in the hope of finding the source of the borax and other salts. After much delay, work was finally commenced in 1887, and carried on under many difficulties, owing to the nature of the ground. The bottom of the lake was found to be of a remarkably sticky, tenacious, plastic clay, described as being "tough as wax." To avoid the difficulty of keeping back the alkaline water by coffer dams or other similar contrivances, the first experimental well was commenced on the ridge before mentioned. It was sunk by spring-pole drills to a depth of three hundred feet. The following is a section carefully kept by Mr. Searles:

1. Two feet salt and thenardite.
2. Four feet clay and volcanic sand containing a few crystals and bunches of hanksite.
3. Eight feet volcanic sand and black tenacious clay with bunches of trona of black shining lustre from inclosed mud.
4. Eight-foot stratum, consisting of volcanic sand in which is found glauberite, thenardite and a few flat hexagonal crystals of hanksite.
5. Twenty-eight feet of solid trona of uniform thickness. Other borings show that this valuable mineral extends over a large area.
6. Twenty-feet stratum of black, slushy, soft, mud, smelling strongly of hydrosulphuric acid, in which there are layers of glauberite, soda and hanksite. The water has a density of 30° Beaumé.
7. Two hundred and thirty feet (as far as explored), of brown clay, mixed with volcanic sand, and permeated with hydrosulphuric acid.

Overlying No. 5, is a thin seam or stratum difficult to penetrate, to which the name "hard stuff" has been given, the exact nature of which is unknown.

Borax is produced at these works by three different methods. By evaporating natural solution of borax; by lixiviation of crude material; and by solution and re-crystallization of tincal. What is known as "crude material" is a somewhat pulverulent, slightly yellowish, amorphous incrustation which yields about eight per cent. of borax when worked on a large scale.

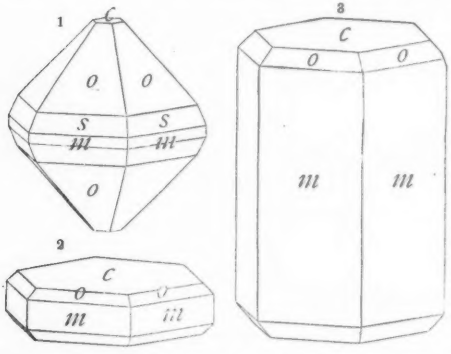
Borax is obtained from this crude material by solution and evaporation The plant, which is very extensive, and owing to the distance and isolated position of the deposits, costly, consists of a large steam flue boiler, and a multitude of boiling and crystallizing tanks, of wood and boiler iron. Steam is conveyed in pipes to the various tanks, instead of utilizing the heat of the sun, which would be more economical and the yield and quality quite as good. The peculiar dryness of the climate is specially favorable for solar evaporation and graduation. Fifty men and thirty-five animals are employed in these works. The product is hauled in wagons to Mohave station, a distance, of about seventy miles, over a sandy desert, so dry and sterile that a supply of water must be hauled in other wagons for the use of men and animals. The fuel used has been generally the sage-brush which is gathered at heavy cost, and thrown under the boilers with pitchforks, like hay into a barn; but recently, California crude petroleum has been substituted.

Hanksite first came to San Francisco in the massive form and was called by the borax miners "Ice," which it certainly resembled. It was examined in the usual manner and found to be an anhydrous sulphate of soda, and was labelled thenardite. No analysis was made and the small proportion of carbonic acid was overlooked in the blowpipe examination. The next specimens received were small hexagonal plates, found in the highly concentrated waters of the lower lake. These went to New Orleans with the California exhibit, and were shown at the exposition of 1884–5, where they attracted the attention of Mr. William Earl Hidden, who was the first to suspect a new species. The results of his study of the crystals led to a paper by him, which he read before the New York Academy of Sciences, May 25, 1885.*

The magnificent crystals recently discovered were taken from the sandy clay No. 2 of the section, and No. 7, seventy feet or more below the surface. There were not more than

* This Journal, xxx, 133, 1885.

thirty in all. About the time of their discovery, work was suspended. It will not be resumed for several months, when it is to be hoped that enough will be obtained to supply the scientific world with specimens. The form of these crystals is shown in figure 1,* the planes present are: c(0001, O), m (10$\bar{1}$0, I), o (10$\bar{1}$1, 1), s(20$\bar{2}$1, 2).



What Mr. Searles calls "bunches of hanksite" are aggregations of flat hexagonal plates joined together in a confused irregular manner. They vary in size from an inch or less in diameter to eight inches or more. One of these crystals is shown in figure 2. The crystals also vary in size, the largest being three inches, and the smallest half an inch or less in diameter. Some of the bunches have been accidentally subjected to the action of comparatively pure water, by which partial solution has taken place, not only marring the beauty of the individual crystals, but leaving the clusters in a dilapidated, cavernous condition. In the dark, concentrated, amber-colored water of the borax lake, they remain unchanged. A rare prismatic form is shown in figure 3.

Hanksite is known to occur also in the borax fields of Death Valley, Inyo County, and there are several known localities in the state of Nevada.

The following minerals have been found associated with borax in San Bernardino County:

Anhydrite, calcite, celestite, cerargyrite, colemanite, dolomite, embolite, gay-lussite, glauberite, gold, gypsum, halite, hanksite, hydrosulphuric acid, natron, soda niter, sulphur, thenardite, tincal, trona.

It is the opinion of the writer that instead of being a rare mineral, hanksite will be found in great abundance, and it will be proved that it plays an important and active part in the metamorphoses that produce gay-lussite, thinolite and perhaps borax.

San Francisco, October 20, 1888.

* These figures have been drawn by Mr. E. F. Ayres of Yale University.

ART. VIII.—*Sperrylite, a new Mineral;* by HORACE L. WELLS.

A SMALL quantity of the remarkable mineral which is the subject of this article was sent to the writer in October of the present year by Mr. Francis L. Sperry of Sudbury, Ontario, Canada, chemist to the Canadian Copper Co. of that place. A few tests sufficed to show that it was essentially an arsenide of platinum and consequently of great interest, since platinum has not been found before, at least as an important constituent, in any minerals except the alloys with the other metals of the platinum group.

Since the time mentioned Mr. Sperry has furnished, with great liberality, an abundance of the material for investigation and has given the following account of its occurrence:

"The mineral was found at the Vermillion Mine in the District of Algoma, Province of Ontario, Canada, a place 22 miles west of Sudbury and 24 miles north of Georgian Bay, on the line of the Algoma Branch of the Canadian Pacific Railway. The mine was discovered in October, 1887, and a 3 stamp mill was put up for the purpose of stamping gold quartz. Associated with this gold ore are considerable quantities of pyrite, chalcopyrite and pyrrhotite, and, at the contact of ore and rock and occupying small pockets in decomposed masses of the ore, there is a quantity of loose material composed of gravel containing particles of copper and iron pyrites. It was in milling this loose material that several ounces of the arsenide of platinum were gathered on the carpet connected with the stamp-mill. Through the kindness of Mr. Charlton, the genial President of the Vermillion Mining Co., all of the mineral that was available was generously placed at my disposal."

It may be mentioned here that Mr. Sperry sent me, a few weeks before sending the arsenide, a minute bead which he had obtained in making a fire-assay for gold on an ore, consisting chiefly of chalcopyrite and pyrrhotite, which came from the same mine where the arsenide was found but which was not the material in which it actually occurred. This bead on examination proved to be composed largely of metals of the platinum group, and, from the color of the precipitate produced by ammonium chloride, it was thought that it contained a large proportion of iridium, but its small size prevented a satisfactory examination. With this bead in mind, I expected that the new mineral would contain a considerable amount at least of iridium, but, strangely enough, none of this metal was found in it. The material as received consisted of a heavy, brilliant sand composed largely of the arsenide; but intermixed with this a considerable amount of fragments of chalcopyrite,

pyrrhotite and some silicates could be seen. In order to purify the substance it was treated for a short time with warm aqua regia to remove sulphides, etc.; then it was treated for a long time with hot hydrofluoric acid to remove the silicates. After these treatments the sand possessed great brilliancy, but it was found by microscopic examination to contain some transparent grains which on chemical examination proved to be stannic oxide. Prof. S. L. Penfield kindly examined these grains and found that they corresponded perfectly in their optical properties with cassiterite.

Nearly all the grains of the new mineral showed extremely brilliant crystal-faces, though most of the crystals were fragmentary; in size they were mostly between ·05 and ·5^{mm} ($\frac{1}{500}$ and $\frac{1}{50}$ inch) in diameter.

The color of the mineral is nearly tin white or about the same as that of metallic platinum; the fine powder is black.

The specific gravity taken twice on the same 8 grams of material, was 10·420 and 10·424 at 20°; this material was the same that was used for analysis, and, correcting the average of these results for 4·62 per cent of cassiterite, the true specific gravity becomes 10·602.

The sand is not easily wet by water and shows a marked tendency to float when brought to its surface. By placing a shallow layer of water upon the mineral in a vessel it is easy to nearly cover the surface of the water with a continuous layer of the crystals by inclining the vessel repeatedly so that they are brought to the surface. This phenomenon is not due to any oily substance upon the particles, for they float with equal readiness after being boiled with a strong solution of potash and washed with alcohol and ether. When they are floating upon water it is quite difficult to cause them to sink, and when carried to the bottom by a stream of water they frequently carry down small bubbles of air which they completely surround and hold down by their weight. If ether is poured upon water on which they are floating, they remain suspended between the two liquids, and, by agitation, can frequently be made to sink to the bottom in spherical clusters surrounding globules of ether.

The mineral is only slightly attacked by aqua regia; even when it is very finely pulverized and the strongest aqua regia is repeatedly applied with the aid of heat for several days, the solution is only partial.

Pyrognostics.—The mineral decrepitates slightly when heated. In the closed tube it remains unchanged at the fusing-point of glass. In the open tube it gives very readily a sublimate of arsenic trioxide and does not fuse if slowly roasted, but if rapidly heated it melts very easily after losing a part of the arsenic. Perhaps its most characteristic reaction is the follow-

ing: when dropped on a red hot platinum foil it instantly melts, gives off white fumes of arsenic trioxide having little or no odor, and porous excrescences are formed on the platinum which do not differ in color from the untouched foil.

Chemical analysis.—The following analyses of the mineral were made after a considerable amount of preliminary work had been done on it, the results of which confirm these figures.

	I.	II.	Mean.	Ratio.
As	40·91	41·05	40·98÷ 75=·546	·550=2
Sb	0·42	0·59	0·50÷122=·004	
Pt	52·53	52·60	52·57÷197=·267	·274=1
Rh	0·75	0·68	0·72÷104=·007	
Pd	trace	trace	trace	
Fe	0·08	0·07	0·07	
SnO_2	4.69	4·54	4·62	
	99·38	99·53	99·46	

The composition is consequently represented by the formula $PtAs_2$, a small portion of the platinum and arsenic being replaced respectively by rhodium and antimony. In composition this mineral appears to be nearer Wöhler's laurite* than any other mineral now known. The form of both is isometric,† but their composition is apparently not quite analogous since the formula of laurite is given as $RuS_2+\frac{1}{20}Ru_4Os$. It is possible that the latter formula is slightly incorrect since Wöhler used an extremely small quantity (·3145 gram) for his analysis and acknowledged the uncertainty of his results. It is also to be noticed that the composition of the mineral corresponds to that of the artificial platinum arsenide made by Murray.‡ The writer has confirmed the composition of this artificial arsenide by heating a known weight of platinum to redness and passing over it vapor of arsenic in a current of hydrogen. The following are the results of the experiments:

	Pt taken.	As absorbed.	Ratio. Pt	As
I	·3806	·2922	1	2·02
II	·5725	·4354	1	2·00
III	1·0657	·8112	1	2·00

It was noticed in these experiments that the arsenic combines with the platinum with incandescence and the alloy melts even below a red heat after a part of the arsenic has been taken up. At the end of the operation, however, the fused globule solidifies, throws out peculiar, arborescent forms and the $PtAs_2$ remains as a porous and very brittle mass which is neither fused nor changed in composition when heated to bright red-

* Ann. Ch. Pharm., cxxxix, 116.

† See next article for crystalline form of Sperrylite. ‡ Watt's Dictionary.

ness in hydrogen. In its behavior with solvents and its pyrognostic properties the artificial compound agrees exactly with the natural mineral.

Method of analysis.—The amount of substance taken for each analysis was about 1·5 g. The pulverized substance was gradually heated in a current of chlorine gas and the volatile chlorides were absorbed by water in a receiver.* This liquid was made ammoniacal after adding a very small quantity of tartaric acid to keep the small amount of antimony in solution and the arsenic was determined as magnesium pyroarseniate. From the filtrate from the ammonium magnesium arseniate, antimony and a trace of platinum were precipitated as sulphides, the sulphide of antimony was dissolved in strong hydrochloric acid, the sulphide was reprecipitated, filtered on asbestus and weighed after proper heating in a current of carbon dioxide, while the trace of platinum sulphide was ignited and the residue was added to the main part of the platinum left by treatment with chlorine. This part was treated with dilute aqua regia; this left an insoluble residue consisting of cassiterite and a finely divided black substance which had been found by previous qualitative tests to be rhodium. This residue was fused with sodium carbonate and sulphur, the insoluble rhodium sulphide formed was ignited in air, then in hydrogen and weighed, while the tin was determined as stannic oxide in the usual way. The purity of the rhodium was shown by its complete solubility in fused potassium disulphate, also by finding that it gave no sodium double chloride soluble in alcohol after ignition with sodium chloride at a faint red heat in a current of chlorine. About $\frac{2}{3}$ of the total rhodium was found here. The purity of the stannic oxide was shown by reducing it in hydrogen and dissolving the metal in hydrochloric acid.

The solution in aqua regia containing platinum with a little rhodium and iron and a trace of palladium was treated for the platinum metals essentially by the method of Claus;† the main variations being a repeated separation of platinum from rhodium and the weighing of platinum as metal. A distinct but extremely small precipitate of palladium cyanide was obtained, but the amount of palladium was too small to sensibly affect the balance when an attempt was made to weigh it.

The name.—The writer takes great pleasure in naming this interesting mineral after Mr. F. L. Sperry, to whose efforts this investigation is due.

Sheffield Laboratory, Dec. 12, 1888.

* Preliminary experiments with the artificial compound, $PtAs_2$, had shown that all the arsenic passes off in this operation if the heat is applied slowly enough so that the substance does not melt after losing a part of its arsenic

† Rose und Finkener, analytische Chemie, 6te Aufl., vol. ii, p. 2 :6.

Art. IX.—*On the Crystalline form of Sperrylite;* by S. L. Penfield.

The crystalline form of sperrylite is isometric; pyritohedral. Simple cubes are common, octahedrons are exceptional, while the majority of the crystals, which are usually fragmentary, show combinations of cube and octahedron. The first crystal which was selected for measurement was a fragment showing the above mentioned combination; one of its central octahedral faces being imperfect, the best measurements were obtained from a cubic to an adjoining octahedral face. The results, which are given below, are very satisfactory considering the small size of the crystals, and prove that the mineral is isometric; it may also be said that where the reflections were sharpest and best the values came nearest to the theoretical.

			Calculated.
$a \wedge o$	$001 \wedge \bar{1}11$	54° 34′	54° 44′
"	$001 \wedge 1\bar{1}1$	54 46	"
"	$100 \wedge 1\bar{1}1$	54 35	"
"	$100 \wedge 11\bar{1}$	54 45	"
$a \wedge a$	$100 \wedge 001$	90 2	90°

At first only the above mentioned forms were detected, but on sifting off the smallest crystals and carefully looking over the largest ones some were detected which suggested pyrite forms. The chemical relation of the mineral $PtAs_2$ to the minerals of the pyrite group caused me to make a very careful search for pyritohedral forms, which was fortunately successful. Cubes with replacement of the edges are very exceptional; a number of them were found, however, and in all cases the replacements, which were necessarily small and frequently failed on some of the edges, had the arrangement required by the combination of cube and pyritohedron. The best crystal selected for measurement was the top of a cube measuring $0{\cdot}35 \times 0{\cdot}45^{mm}$ in combination with octahedron and two small but well developed pyritohedral faces; the latter gave very good reflections. The measured angles are

			Calculated.
$i\text{-}i \wedge i\text{-}2$	$001 \wedge 102$	26° 28′	26° 34′
"	$001 \wedge \bar{1}02$	26 31	"

Another crystal which was carefully measured was an irregular one measuring 0·35 and $0{\cdot}55^{mm}$ in two diameters; this was developed in all directions; in one zone the four cubic and four pyritohedral faces were all present in their proper order and gave satisfactory measurements, in a second zone four cubic and two pyritohedral faces were found and in the third zone four cubic and one truncating rhombic dodecahedral face

were detected; this is the only case in which a dodecahedral (110) face was found. In a few cases the characteristic combination of octahedron and pyritohedron was detected, but the latter faces were always very small. These results are most satisfactory and from the number of crystals which have been examined and measured, in all of which the pyritohedral faces occur with their proper order and arrangement, the hemihedral nature of the mineral can not be doubted. Some of the crystals are somewhat rounded and probably other isometric forms are present but none of them were determined. The faces on the crystals are usually very flat and must be very highly polished to give such satisfactory measurements. It may also be noted that the cubic faces are not usually striated parallel to their intersection with the pyritohedron as is common in pyrite, although it was a slightly striated cube which first called my attention to the pyritohedral nature of the crystals.

The first attempts to determine the pyritohedral faces of the mineral yielded results which were very perplexing but which are not without interest. Cubes with pyritohedral faces were found and measured giving repeatedly the angle of cube on pyritohedron between 29½° and 30½°, the pyritohedral faces always giving poor reflections. The calculated value of i-i on i-$\frac{7}{4}$, $001 \wedge 407$ being 29° 45′. The pyritohedral arrangement of the faces was perfect but I always failed to find the common pyrite form $\frac{1}{2}(i\text{-}2)$ $\pi(210)$. On talking this over with Professor Wells he stated that all of the material which he had given to me had been cleaned, as for analysis, with aqua-regia and that perhaps the acid had had some action on the faces, as the mineral was not wholly insoluble. He therefore gave me some material which had not been cleaned with acid and the results which were given earlier in this article were obtained from it. The aqua-regia seems to have no effect on the cubic and octahedral faces, at least not enough to diminish their power of reflecting light, for the first measurements given in the article of cube on the octahedron were obtained from a crystal which had been cleaned with acids; the acids have, however, a very decided action on the pyritohedral faces, nearly destroying their power of reflecting light and perceptibly changing their angle.

To sum up the crystallographic observations, the crystals usually show the combination of cube 100, i-i; octahedron 111, 1; pyritohedron $\pi(210)$, $\frac{1}{2}(i\text{-}2)$ and very rarely dodecahedron 110, i. Taken in connection with the chemical results the mineral takes a place in our classification in the pyrite group where an atom of a metal, usually Fe, Co or Ni is united with two atoms of either S, As or rarely Sb, or an isomorphous mixture of them. As this is the first time that platinum has been found in combination as a mineral it may be noted that

Fe, Co, and Ni and the metals of the platinum group fall in the same series in Mendelejeff's periodic system of the elements, which gives additional grounds for putting this mineral in the pyrite group.

The hardness of the mineral is between 6 and 7, which was determined by placing selected crystals on a bright feldspar surface, pressing down on them with a soft pine stick and rubbing back and forth; the sperrylite repeatedly cut into the feldspar but could not be made to scratch quartz. The crystals have no distinct cleavage but are very brittle and break with an irregular, probably conchoidal fracture.

Mineralogical Laboratory, Sheffield Scientific School, Dec. 12th, 1888.

SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *On the Vapor-density of the Chlorides of Indium, Gallium, Iron and Chromium; and on two new Chlorides of Indium.*—Nilson and Pettersson have determined the vapor density of the chlorides of indium, gallium, iron and chromium by V. Meyer's method, employing for the purpose vessels made either of hard Thuringen glass or of porcelain. In the course of their researches upon the indium chlorides they discovered two new ones; the mono-chloride, having a vapor density of 5·402 at 1300°–1400° and the formula InCl; and the dichloride $InCl_2$ whose vapor density was found to be 6·885 at 1100°. The third chloride carefully purified gave a vapor density of 8·156 at 606°; of 7·391 at 850°; of 6·716 at 1048; and of 6·234 at 1100°–1200°. The formula $InCl_3$ gives 7·548; and hence the authors consider this formula correct. The higher chloride of gallium gave the vapor density 8·846 at 350°; 6·118 at 440°; 6·144 at 606°, and 5·185 at 1000°–1100°; corresponding to the formula $GaCl_3$ which requires 6·081. The lower chloride gave a density of 4·823 at 1000°–1100° and 3·568 at 1300°–1400°; the formula $GaCl_2$ requiring 4·859. Ferrous chloride at 1300°–1400° gave a vapor density of 4·340; and at 1400°–1500°, one of 4·292; the formula $FeCl_2$ requiring 4·375. The higher chloride of chromium gave values varying from 6·135 at 1065° to 4·580 at 1350°–1400°, the formula $CrCl_3$ requiring 5·478. The lower chloride gave a vapor density of 7·800 at 1300°–1400°; 7·278 at 1400°–1500°, and 6·224 at 1500°–1600°. At a higher temperature the authors believe it would reach 4·256 the value required by the formula $CrCl_2$.—*J. Chem. Soc.*, liii, 814, October, 1888. G. F. B.

2. *On the Vapor-density of Ferric chloride.*—Friedel and Crafts have determined the vapor density of ferric chloride by the method of Dumas taking the same precautions as with alumi-

num chloride.* In a nitrogen atmosphere in which the partial pressure of the vapor was 0·75, they obtained at 433° the value 10·86 as a mean of two experiments, the formula Fe_2Cl_6 requiring 11·25. The vessel used could be examined readily during the operation; and it was found that even at 440°, the ferric chloride was decomposed into ferrous chloride and chlorine; the former not being volatile at this temperature was deposited in crystals on the walls of the vessel, and combined again with the chlorine on cooling. The authors thus explain the results obtained by V. Meyer and Grünewald.† To avoid this dissociation, further experiments were made in an atmosphere of chlorine, in which the chloride has only a slight pressure. At temperatures between 321° and 442° the density remained nearly constant at about the value required by theory. The chloride boiled at 280°–285.—*C. R.*, cvii, 301; *Ber. Berl. Chem. Ges.*, xx, (Ref.) 579, October, 1888. G. F. B.

3. *On the Vapor Density of Gallium chloride.*—Friedel and Crafts have also determined by the same method the vapor density of the higher chloride of gallium. This density decreases as the temperature rises, falling from 10·6 at 307° to 7·8 at 440°. At 237° –273° approximately constant values are obtained agreeing closely with the theoretical value 12·2 calculated from the formula Ga_2Cl_6. Constant values corresponding to the formula $GaCl_3$ were not observed.—*C. R.*, cvii, 306; *Ber. Berl. Chem. Ges.*, xxi, (Ref.) 580, October, 1888. G. F. B.

4. *On the Molecular Mass of Sulphur, Phosphorus, Bromine and Iodine in Solution.*—Paterno and Nasini have made use of Raoult's method for the purpose of determining the molecular mass of sulphur, phosphorus, bromine and iodine in solution, the researches of van't Hoff upon the osmotic pressure of liquids leading directly to the assumption that the law of Avogadro holds good in dilute solutions as in gases, the osmotic being substituted for the atmospheric pressure. In the case of sulphur, the solvent used was benzene, the experiments being made with solutions of different strengths. The depression-coefficient obtained was constant and led to the molecular formula S_6, corresponding to that obtained by means of the vapor-density at 500°. For bromine, solutions in water and in glacial acetic acid were used; and numbers were obtained leading to the formula Br_2. For iodine, the solvents employed were benzene and glacial acetic acid. For very dilute solutions in the former, the results corresponded to the formula I_2. But for solutions in the latter, values were obtained leading to a formula between I and I_2, although the molecular depression was constant. The phosphorus employed was not quite pure. But its solution in benzene gave a value intermediate between the formulas P_2 and P_4.—*Ber. Berl. Chem. Ges.*, xxi, 2153, July, 1888. G. F. B.

5. *On the Atomic Mass of Osmium.*—The atomic mass of osmium has been determined by Seubert, by reducing ammonium

* This Journal, III, xxxvi, 465, Dec., 1888.
† See this Journal, III, xxxv, 494, June, 1888.

or potassium osmiochloride in a current of hydrogen, the chlorine being also determined. The ammonium osmiochloride was prepared by adding ammonium chloride to an alcoholic solution of osmium chloride. The potassium salt was obtained by heating the metal mixed with potassium chloride in a current of chlorine. A second portion of the ammonium salt was prepared by precipitating sodium osmiochloride with ammonium chloride. The results of analysis gave 191·12 as the mean of several experiments. The author thinks this too high and gives 190·8 as the more probable atomic mass.—*Ber. Berl. Chem. Ges.*, xxi, 1839, June, 1888. G. F. B.

6. *A Class Book of Elementary Chemistry;* by W. W. Fisher, M.A., F.C.S., Aldrichian Demonstrator of Chemistry. 12mo, pp. xvi, 272. Oxford, 1888. (Clarendon Press).—In his preface the author states that, in the main he has followed in his selection of subjects the syllabus of the Oxford Local Examinations for Senior Candidates and the Examination of Women. After a few pages upon the laws of chemical combination, atomic weights and formulas, he takes up hydrogen, oxygen, water, nitrogen, air, carbon, sulphur, etc. In chapter xv, he considers quantivalence and the periodic law, and then discusses the metals, closing with chapters on specific, atomic and molecular heats, and the physical properties of gases. It is one of the best books of its grade that we have seen recently. The cuts are clear and well selected and the mechanical execution of the book is good. G. F. B.

7. *Examples in Physics;* by D. E. Jones, B.Sc., Lecturer on Physics at the University College of Wales, Aberystwyth. 16mo, pp. viii, 261. London and New York, 1888. (Macmillan & Co.).—This little book contains a carefully prepared series of physical problems, over one thousand in number, intended to test both the student's knowledge and his facility of applying it practically. The value of such tests is beyond dispute. The introductory chapter is a concise exposition of units and dimensions, and the subsequent chapters are devoted to Dynamics, Hydrostatics, Expansion, Specific and Latent Heat, Conductivity and Thermodynamics, Light, Sound, Magnetism, Electrostatics, and Current Electricity. We have failed to find at the end of the book, however, the four-place logarithm tables mentioned on pages 19 and 21. The problems themselves are most excellent, many of them being selected from examination papers of repute. The book will be found a valuable adjunct in the physical class room. G. F. B.

8. *Oxygen lines in the Solar Spectrum.*—M. Janssen ascended Mt. Blanc on October 13th, and succeeded on October 15th and 16th in making some observations under the most favorable conditions. The results show that both the band and lines of oxygen, identified previously by him in the solar spectrum, are due entirely to the earth's atmosphere. The systems of bands, those in the red, in the yellow, and the blue, the intensity of which varied with the square of the density of the absorbing oxygen,

were altogether wanting, and the groups of dark lines A, B and α which M. Janssen had previously found to vary as the simple density, were so much enfeebled as to leave little doubt that they too would disappear, could we entirely eliminate the effects of the earth's atmosphere.—*Nature*, Nov. 8, 1888, p. 40. J. T.

9. *Effect of staining upon dry plates.*—"At the meeting of the Physical Society of Berlin, Nov. 2, Professor KUNDT exhibited a number of photographs of spectra photographed upon dry plates which had been stained with various substances. The plates stained with chlorophyl gave especially interesting results. The spectra obtained upon them consisted of a bright strip ending near F followed by a dark portion intercepted by an extremely bright line at the spot where the absorption band of chlorophyl is present in the red. Plates stained with eosin similarly showed a bright strip corresponding to the absorption band of this substance in the yellow, whose brightness was much greater than that of the rest of the spectrum. These experiments showed that the rays of light which are absorbed by the above coloring matter exert an extremely active chemical action on the plate. Experiments made with a view to determining whether absorption of light has a similar effect on fluorescence yielded negative results. It still remains to investigate whether the maximum brightness of the spectrum photographed on a plate stained with chlorophyl corresponds exactly with the absorption found of this substance, taking into account the influence of the solvent used for the solution of the chlorophyl on the position of its absorption band."—*Nature*, Nov. 29, 1888, p. 120. J. T.

10. *Electrical currents produced by light.*—STOLETOW employed the following apparatus in his investigation upon this subject. A glass cylinder is closed at one end by a quartz plate which is silvered in net form, though the other end of the cylinder passes a micrometer screw terminating in a silvered iron plate. This iron plate and the silver net work on the quartz plate served as electrodes. The cylinder was filled with various gases which were submitted to the rays from an electric light. No difference could be perceived in the behavior of moist and dry air and hydrogen at ordinary pressures. Carbonic acid, however, gave double the effect of the above mentioned gases. With diminishing pressures the effect increases until the pressure of 3–4 mm. is reached and then diminishes.—*Comptes Rendus*, 107, 1888, pp. 91–92. J. T.

II. GEOLOGY AND NATURAL HISTORY.

1. *Cambrian of Bristol County, in Eastern Massachusetts.*—Professor N. S. SHALER has reported, in the Bulletin of the Museum of Comparative Geology of October, 1888 (vol. xvi, No. 2), the discovery of Cambrian fossils near Attleborough, a few miles from the northeast angle of Rhode Island. The region lies on the west of the main belt of the Carboniferous of the Narragansett basin. East of it is an area of gneiss, which is probably

pre-Cambrian. On the colored geological map accompanying the paper, the Cambrian is made to pass south and southwest over Falls Village into Rhode Island. The rocks of the Cambrian are shales and conglomerates. The Cambrian area of Braintree, where the *Paradoxides Harlani* occurs, is twenty-five miles to the north; but it was not possible to make out the stratigraphic relations between the two. The fossils discovered are: *Obolella crassa* Hall, *Fordilla Troyensis?*, *Scenella reticulata* Billings, *Stenotheca rugosa*, *Stenotheca curvirostra*, sp. n., *Platyceras primævum* Billings, *Pleurotomaria* (*Raphistoma*) *Attleborensis*, sp. n., *Hyolithes quadricostatus*, sp. n., *H. communis* var. *Emmonsi* Ford, *H. Americanus* Billings, *H. princeps* Billings, *H. Billingsi* Walcott?, *Hyalithellus micans* Billings, *Salterella curvatus*, sp. n., *Aristozoë?*, *Microdiscus bellimarginatus*, sp. n., *M. lobatus* H., *Paradoxides Walcotti*, sp. n., *Ptychoparia mucronata*, sp. n., *P. Attleborensis*, sp. n. The fossils are figured on two plates. In the study of the fossils, Professor Shaler was aided by Mr. A. F. Foerste. The authors remark that while the fossils are those of the "Olenellus group," the beds contain no species of Olenellus, and that the presence of a Paradoxides "diminishes the importance of the Paradoxides division of the Cambrian." The species of Paradoxides is very small, or the specimen is young.

2. *Silicified wood of Arizona;* by F. H. Knowlton.—A large trunk of silicified wood from the vicinity of Fort Wingate, Arizona, which has been on exhibition for several years at the U. S. National Museum, Washington, has been studied by Mr. Knowlton, and named (Proc. U. S. Nat. Mus., 1888, p. 1) *Araucarioxylon Arizonicum*. A plate (Plate I) accompanies the paper. Mr. Knowlton also describes two new species of fossil coniferous wood from Iowa and Montana, which he refers to the genus *Cressinoxylon* (Plates II, III).

3. *Dahllite, a new mineral.*—Brögger and Bäckström have described a new mineral from the apatite region in the parish of Bamle, Norway. It occurs as a rather thin crust, which has a rounded lustrous surface and a fibrous structure, the fibers being perpendicular to the base of massive reddish apatite. The color is pale yellowish white or reddish yellow, but appears colorless in a thin section; it is translucent and somewhat resembles chalcedony. It is optically negative. The hardness is about 5 and the specific gravity 3·053. An analysis gave the following results:

P_2O_5	CO_2	CaO	FeO	Na_2O	K_2O	H_2O
38·44	6·29	53·00	0·79	0·89	0·11	1·37=100·89.

This corresponds essentially to the formula $4Ca_3P_2O_8+2CaCO_3+H_2O$. The microscopic and chemical examination convinced the authors that the mineral was homogeneous, notwithstanding its remarkable composition.—*Œfv. Vet-Akad. Förhandl.*, p. 493, 1888.

4. *Das Protoplasma als Fermentorganismus;* von Professor Dr. Albert Wigand. Marburg, 1888, pp. 294.—Few scientific

men, upon the summons of failing health, relinquish their work with feelings of greater disappointment than the late Professor Wigand of Marburg. Attached to the manuscripts left by him was this touching inscription, "Folgende von mir festgestellte Thatsachen und Beobachtungen wurden ignoriert oder todtgeschwiegen." Some of these manuscripts edited by an assistant, Dr. Dennert, form the present work. A few of the facts have been given before, and many of the speculations thereon have already been published in other forms. Having these papers before us, it is fair to ask the reason of the neglect of which Wigand complained. The style is not obscure, but the course of the argument is very tedious and one feels compelled to inquire once in a while whether the task of reading it will pay. This defect has diminished the value of about all the scientific work done by Wigand, but this will not alone explain the utter neglect. If one remembers that almost, if not quite, alone among teachers of science in Germany, Wigand was up to the last an opponent of Darwinism, giving much of his time to controversial writings, the neglect is measurably accounted for. The extent to which his antagonism to Darwinism influenced all his thought is shown by an expression which he once used in a conversation with Dr. Dennert, "my whole life has revolved around Tannin, Darwinism and Bacteria."

We may smile at this odd collocation, but it expresses a truth. His researches in regard to Tannin possesses much merit, and were justly viewed by the author as entitling him to higher recognition than he received. His writings on Darwinism are speculative and unconvincing but they demanded a large share of his energy. The results of his studies regarding the last subject, Bacteria, we have now in part before us. Although the treatise is divided into three distinct portions, they may be considered for practical purposes as one, and embodying a single hypothesis. Without doing any injustice to the author, this hypothesis may be given in a few words, namely, that organized matter (protoplasm and its active living derivatives), possess the power under certain circumstances of being broken up and converted into minute organisms (bacteria in the widest signification). This hypothesis of transformation or "anamorphosis" is, in one sense, the logical outcome of ideas which the author expressed in a now forgotten work of a partly popular character, Der Baum.

The experimental part of the author's work can be fairly illustrated by a single case (No. XI), in which, having taken every precaution for securing perfect freedom of all his apparatus and appliances from germs (and, as he says, being assisted by Dr. Mueller who was familiar with Koch's methods), he introduced a fragment of carefully-washed muscle into a sterilised receptacle, where, after being kept a fortnight, at a temperature of 35° C., the organized matter was found to be filled with bacterial forms. These forms he concludes must have come from the anamorphosis of the protoplasmic matter. The experiment recalls those reported by Béchamp and is open to the same criticism.

Wigand's experiments cover many kinds of organized matter, and all of them are interpreted by him in the same manner, namely as proving that these organisms which cause and accompany putrefaction, etc., may or *must* arise from the transformation of protoplasm. According to him we need not postulate in any case the pre-existence of germs as necessary to putrefaction. The author touches with his hypothesis many points in physiology and pathology. G. L. G.

5. "*Ringed*" *Trees.*—W. L. Goodwin, Queen's University, Kingston, gives in the Canadian Record of Science, for October, 1888, the following details regarding a remarkable case of survival of a pine tree after girdling. The case came under his observation in the summer of 1883. The tree is "a common pine tree which had been ringed several years before I saw it,—just how many I cannot say. The tree stands at the edge of the pine woods of Studley, Halifax, Nova Scotia, and is one of two rising from a common trunk which bifurcates immediately above the surface of the soil. The trees are about 22 feet high, and begin to branch freely at about six feet from the ground. The ring is about four feet from the fork and is eight inches broad. The exposed wood is dead and no signs of life appear within half an inch of the surface. That the tree has grown considerably since it was ringed is shown by the following measurements made this summer:

Circumference below ring,	19¼ inches.
Circumference above ring,	26½ inches.

The diameter of the tree has thus become two inches greater above than it is below the ring. The condition of the bark and cambium layer below the wound shows that the surface of the tree has died for a considerable distance (over six inches). Above the wound the bark and cambium are living and seem to have pushed down over the scar about half an inch. The same process had been evidently begun below the ring before the death of the cambium layer. From measurements made five years ago, I should judge that the tree must have been ringed at least ten years before that date, so that the tree has survived its injury probably fifteen years. Unfortunately the notes of the first measurements are not at hand for comparison. At that date the ringed tree seemed almost as thrifty as its companion, but the foliage showed some signs of imperfect nutrition. At present the tree is in much poorer condition; many of its branches being dead and the foliage scanty on those that are living."

Cases of survival after the injury by girdling or "ringing," have been noticed by many observers, but this is, on the whole, the most striking that has yet come to our notice in this climate. On the Pacific coast cases of survival of orange and olive trees are not rare, but they are not so difficult to explain as this of a pine. G. L. G.

6. *A Provisional Host—Index of the Fungi of the United States;* by W. G. Farlow and A. B. Seymour. Cambridge,

1888, pp. 51.—This, the first part of a most important work, comprises the polypetalæ. Under each species are enumerated the species of fungi reported as living thereon. When the number is small, the names are given in alphabetical order, but, where the number is large, the species are placed under their proper orders, and there alphabetically arranged. A list prepared with the care which has been given to every page of this work, is not only a convenience to some mycologists and a necessity to others, but it exerts a useful influence from its conservative tendency. It will possibly check the multiplication of specific names in this too inviting field for the making of new species; in fact the hope that this might be the case, was one of the inducements which has led to its publication. The great amount of time and labor given to the preparation of a critical index like this can be appreciated only by those who have seen its slow growth under the untiring hands of its authors. G. L. G.

7. *Bibliotheca Zoologica II, bearbeitet von* Dr. O. TASCHENBERG, 6te Lieferung, sig. 201–240, pp. 1651–1970. Leipzig, 1888 (Wm. Engelmann).—The sixth part of this important work, devoted to the bibliography of Insects, including the Hemiptera, Aphaniptera, Diptera and Lepidoptera, has recently been issued.

Bulletin of the N. H. Society of New Brunswick. No. VII, (Saint John, 1888), contains a paper by W. F. Ganong, on the Echinodermata of New Brunswick; on the Mollusca of the Oyster beds of New Brunswick, by W. H. Winkley; and on the question, Does our Indigenous Flora show a recent change of climate, by J. Vroom

The Geological Record for 1880–1884, inclusive; a list of publications on Geology, Mineralogy and Paleontology published during these years, etc. Edited by William Topley and Charles Davies Sherbon. Vol. I. Stratigraphical and Descriptive Geology. 544 pp. 8vo. London, 1888 (Taylor and Francis).

A short account of the History of Mathematics by Walter W. Rouse Ball. 464 pp. 12mo. London and New York, 1888 (Macmillan and Co.).

Bulletin No. 47, of the U. S. Geol. Survey, contains analyses of waters of the Yellowstone National Park by F. A. Gooch and J. E. Whitfield.

Thirty thousand years of the Earth's Past History, read by aid of the discovery of the Second Rotation of the Earth, by Maj. Gen. A. W. Drayson, F.R.A.S. London, 1888 (Chapman & Hall).

Missouri Rainfall, by Prof. F. E. Nipher. 6 pp. 8vo, with maps of the rainfall for the year and each month of the year. St. Louis, 1888.

Darwinism, a brief history of the Darwinian theory of the origin of species, by Dr. D. S. Jordan. 64 pp., 12mo. Chicago, 1888 (A. B. Gehman & Co.).

Soaps and Candles. Edited by James Cameron, F. I. C. 306 pp. 12mo. Philadelphia, 1888 (P. Blakiston, Son & Co.).

A Text Book of Euclid's Elements, for the use of schools. Parts I and II, containing Books I–VI, by H. S. Hall and F. H. Stevens. 382 pp., 12mo. London and New York (Macmillan & Co.).

Elemente der Palæontologie bearbeitet von Dr. G. Steinmann, unter Mitwirkung von Dr. Ludwig Döderlein. 1te Hälfte (Bogen 1–21). Evertebrata (Protozoa-Gastropoda). 336 pp. 8vo. Leipzig, 1888 (Wm. Engelmann).

Œuvres complètes de Chr. Huygens, publ. par la Soc. Hollandaise des Sciences. The first volume, in 4to, has been recently issued.

GEORGE L. ENGLISH & CO.,

DEALERS IN

MINERALS.

Send for Catalogue. Free to any Address.

RECENT ADDITIONS:

Remarkably modified Topaz Crystals from Mexico: a large and choice lot at very low prices; Topaz Crystals from Stoneham, Maine; Alaska Garnets, extra large, fine and cheap; Topazolites from California, a few good specimens; Modified Rutiles, and Rutilated Quartz from North Carolina; Fluorites, Calcites, Dioptase, Bertrandite and many other desirable minerals from Europe; Colemanites, Hanksites, Phenacites, Bertrandites, Gem Aquamarines, Rhodochrosites, Hübnerite in terminated crystals, Tyrolite, Erinite, Olivenite, and many other rare and fine western minerals.

We believe we have the most varied and complete stock in the United States.

Collections of all kinds in stock and to order.

Minerals by the pound for Blowpipe Analysis.

GEO. L. ENGLISH & CO., Dealers in Minerals,
1512 Chestnut Street, - - Philadelphia, Pa.

BECKER BROTHERS,

No. 6 Murray Street, New York,

Manufacturers of Balances and Weights of Precision for Chemists, Assayers, Jewelers, Druggists, and in general for every use where accuracy is required.

PUBLICATIONS OF THE

JOHNS HOPKINS UNIVERSITY.

I. American Journal of Mathematics. S. NEWCOMB, Editor, and T. CRAIG, Associate Editor. Quarterly. 4to. Volume X in progress. $5 per volume.

II. American Chemical Journal.—I. REMSEN, Editor. Bi-monthly. 8vo. Volume IX in progress. $3 per volume.

III. American Journal of Philology.—B. L. GILDERSLEEVE, Editor. Quarterly. 8vo. Volume IX in progress. $3 per volume.

IV. Studies from the Biological Laboratory.—Including the Chesapeake Zoölogical Laboratory. H. N. MARTIN, Editor, and W. K. BROOKS, Associate Editor. 8vo. Volume IV in progress. $5 per volume.

V. Studies in Historical and Political Science.—H. B. ADAMS, Editor. Monthly. 8vo. Volume VI ready. $3 per volume.

VI. Johns Hopkins University Circulars.—Containing reports of scientific and literary work in progress in Baltimore. 4to. Vol. VII in progress. $1 per year.

VII. Annual Report.—Presented to the President by the Board of Trustees, reviewing the operations of the University during the past academic year.

VII. Annual Register.—Giving the list of officers and students, and stating the regulations, etc., of the University. *Published at the close of the Academic year.*

AMERICAN JOURNAL OF SCIENCE.

FOUNDED BY PROFESSOR SILLIMAN IN 1818.

Devoted to Chemistry, Physics, Geology, Physical Geography, Mineralogy, Natural History, Astronomy, and Meteorology.

EDITORS: JAMES D. DANA and EDWARD S. DANA.

Associate Editors: J. P. COOKE, JR., GEORGE L. GOODALE, and JOHN TROWBRIDGE, of Cambridge, H. A. NEWTON and A. E. VERRILL, of Yale, and G. F. BARKER, of the University of Pennsylvania, Philadelphia.

Two volumes of 480 pages each, published annually in **MONTHLY NUMBERS.**

This Journal ended its *first* series of 50 volumes as a quarterly in 1845, and its *second* series of 50 volumes as a two-monthly in 1870. The monthly series commenced in 1871.

Twenty copies of each original communication are, if requested, struck off for the author without charge; and more at the author's expense, provided the number of copies desired is stated on the manuscript or communicated to the printers of the Journal.

The title of communications and the names of authors must be fully given. Articles should be sent in two months before the time of issuing the number for which they are intended. Notice is always to be given when communications offered. have been, or are to be, published also in other Journals.

Subscription price $6; 50 cents a number. A few sets on sale of the first and second series.

Address the PROPRIETORS,

J. D. and E. S. DANA, New Haven, Conn.

English Editions at Half Price.

THE LEONARD SCOTT PUBLICATION COMPANY beg to announce that during 1889, they will continue to furnish its Subscribers with original sheets of the

Nineteenth Century,
Contemporary Review,
Fortnightly Review.

No American, desirous of keeping abreast of the times, can afford to be without these three great English Monthly Reviews. Their contributors comprise the foremost and ablest writers of the World, and their contents treat of the latest and most important phases of modern thought.

Terms: $4.50 each; any two, $8.50; all three, $12.00; single copies, 40 cents each.

Edinburgh Review.
Quarterly Review.
Scottish Review.

We take great pleasure in announcing that we shall continue exclusive control in America of these two great English Quarterlies, furnishing all subscribers with original sheets.

Under an arrangement with the English publisher, we have exclusive control of the American issue, in original sheets.

Terms: $4.00 each; any two, $7.50; all three, $10.50; single copies, $1.25 cents each.

Blackwood's Magazine. $3.00

Is the leading and most popular monthly of Great Britain The tone of its articles is unexceptionable, rendering it most desirable for the Home Circle. Single copy, 30 cents.

With either Quarterly, $6.50; with two Quarterlies, $10.00; with three Quarterlies, $13.00

Westminster Review.

FIRST MONTHLY ISSUE, APRIL, 1887.

This Review will continue faithful to its mission as an organ of independent thought in respect to social, political, philosophical and religious questions.

Terms: $4.00 per Year; 40 cents per Number.

THE AMERICAN NATURALIST.

An Illustrated Monthly devoted to Natural History and Travel.

Terms: $4.00 per Year; 40 cts. per copy.

Shakespeariana.

—AN AMERICAN MONTHLY.—

Aims to tell the news, and mirror the progress of the Shakespearian world; to encourage the influence of Shakespeare reading, and to offer suggestive courses of study; to be of use in Colleges and Schools, Libraries and Reading Rooms, and to prove of interest not only to Shakespeare specialists, teachers, and reading-circles, but to the actor, the dramatist, and the student of general literature.

Terms: $2.00 per Year; 20 cents per Number.

QUARTERLY INDEX

OF LEONARD SCOTT PUBLICATION CO.'S PERIODICALS.
No. 1. JANUARY, 1887—INDEX FOR 1886.
SUBSEQUENT ISSUES FOR EACH QUARTER.

Terms: 25 cents per Year; 10 cents per Number.

All Post Paid throughout the United States and Canada.

Leonard Scott Publication Co.,

SAM'L P. FERREE, Treas. **501 Chestnut Street, Philadelphia.**

CONTENTS.

Page

ART. I.—The History of a Doctrine; Address by S. P. LANGLEY 1

II.—Description of the new mineral, Beryllonite; by EDWARD S. DANA and HORACE L. WELLS. With Plate I 23

III.—The Iron Ores of the Penokee-Gogebic Series of Michigan and Wisconsin; by C. R. VAN HISE. With Plate II 23

IV.—Recent Observations of Mr. FRANK S. DODGE, of the Hawaiian Government Survey, on Halema'uma'u and its debris-cone; by JAMES D. DANA 48

V.—Notes on Mauna Loa in July, 1888 51

VI.—A Quartz-Keratophyre from Pigeon Point and Irving's Augite-Syenites; by W. S. BAYLEY 54

VII.—On the occurrence of Hanksite in California; by HENRY G. HANKS 63

VIII.—Sperrylite, a new Mineral; by HORACE L. WELLS 67

IX.—On the Crystalline form of Sperrylite; by S. L. PENFIELD 71

SCIENTIFIC INTELLIGENCE.

Chemistry and Physics—On the Vapor-density of the Chlorides of Indium, Gallium, Iron and Chromium: and on two new Chlorides of Indium NILSON and PETTERSSON: On the Vapor-density of Ferric chloride, FRIEDEL and CRAFTS, 73.—On the Vapor-density of Gallium chloride, FRIEDEL and CRAFTS: On the Molecular Mass of Sulphur, Phosphorus, Bromine and Iodine in Solution, PATERNO and NASINI: On the Atomic Mass of Osmium, SEUBERT, 74.—A Class Book of Elementary Chemistry, W. W. FISHER; Examples in Physics, D. E. JONES: Oxygen lines in the Solar Spectrum, M. JANSSEN, 75.—Effect of staining upon dry plates, KUNDT: Electrical currents produced by light, STOLETOW, 76.

Geology and Natural History—Cambrian of Bristol County, in Eastern Massachusetts, N. S. SHALER, 76.—Silicified wood of Arizona, F. H. KNOWLTON: Dahllite, a new mineral, BRÖGGER and BÄCKSTRÖM: Das Protoplasma als Fermentorganismus, ALBERT WIGAND, 77.—"Ringed" Trees, W. L. GOODWIN: A Provisional Host, an Index of the Fungi of the United States, W. G. FARLOW and A. B. SEYMOUR, 79.—Bibliotheca Zoologica II, bearbeitet von O. TASCHENBERG, 80.